M.VASILYEV

METALS
AND
MAN

КАЛЬЦИЙ 3d¹4s² СКАНДИЙ 3d¹4s² ТИТАН 3d²4s²

29 63,546 **Cu**	30 65,37 **Zn**	31 69,72 **Ga**	32 72,59 **Ge**
63,65	64	69,71	70,72-74
	66-68		76
	70		
(3d¹⁰) 4s¹ МЕДЬ	3d¹⁰4s² ЦИНК	4s²4p¹ ГАЛЛИЙ	4s²4p² ГЕРМАНИЙ

Rb 85,47 37	**Sr** 87,62 38	**Y** 88,905 39	**Zr** 91,22 40
85	84	89	90-92
87°	86-88		94 96
5s¹ РУБИДИЙ	5s² СТРОНЦИЙ	4d¹5s² ИТТРИЙ	4d²5s² ЦИРКОНИЙ

47 107,868 **Ag**	48 112,40 **Cd**	49 114,82 **In**	50 118,69 **Sn**
	106 108	113	112
	110-112	113°	114-120
107,109	113,114 116	115°	122 124
4d¹⁰5s¹ СЕРЕБРО	4d¹⁰5s² КАДМИЙ	5s²5p¹ ИНДИЙ	5s²5p² ОЛОВО

Cs 132,905 55	**Ba** 137,34 56	**La** 138,91 57	58-71 **Hf** 178,49 72
133	130 132	138°	174
	134-138	139	176-180
6s¹ ЦЕЗИЙ	6s² БАРИЙ	5d¹6s² ЛАНТАН	* 5d²6s² ГАФНИЙ

79 196,967 **Au**	80 200,59 **Hg**	81 204,37 **Tl**	82 207,19 **Pb**
	196	203,205	204,206-208
	198-202		
197	204		6s²6p²
(5d¹⁰)6s¹ ЗОЛОТО	5d¹⁰6s² РТУТЬ	6s²6p¹ ТАЛЛИЙ	СВИНЕЦ

[223] 87	[226] 88 **Ra**	[227] 89 **Ac**	90-103 **Ku** 104
	(218)		
	220-224		* КУРЧАТОВИЙ

M. VASILYEV

●METALS
AND
MAN

В. ВАСИЛЬЕВ

МЕТАЛЛЫ И ЧЕЛОВЕК

На английском языке

CONTENTS

1

"LUSTROUS BODIES
THAT CAN BE FORGED..."
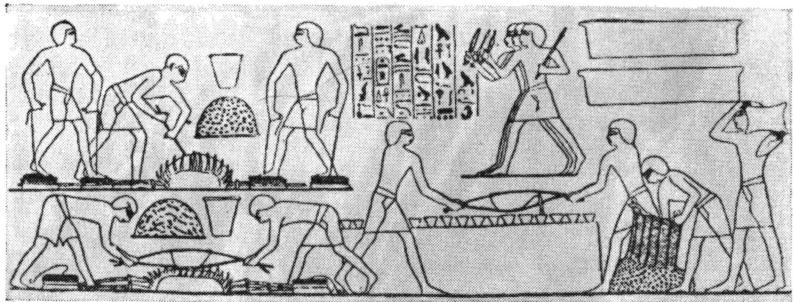
It is a very old legend; it has come down to us from more than thirty centuries ago.

As it goes, after the magnificent Temple at Jerusalem was built for him, King Solomon held a feast for the builders. He went out of his way to treat them to all he had. Even his throne was to be given at the feast to the best among the best, the man who had done exceptional services for the project.

King Solomon stepped down from his gemmed throne of gold, descended the steps covered with purple velvet, and stood modestly among the masons, carpenters, silversmiths and bone-carvers. The same moment a man came out of the crowd, went up the steps and sat down on the throne. The great king frowned in wrath.

"What are you and by what right have you taken this place?" he asked menacingly.

Instead of a reply, the stranger held out his hand imperiously towards the masons and asked them:

"Who has made your tools?"

"A smith has," was the answer.

"And yours?" the stranger's hand pointed at the carpenters.

"A smith," they said.

"And yours?"

Everyone the stranger asked said:

"A smith made the tools we built the Temple with."

Then the stranger turned to the king:

"I am a smith. Am I not entitled to take the place Your Majesty promised to give today to the person who has done the most for the Temple?"

That is how the legend goes. What it means is that metals are the foundation of everything. Or was this so centuries ago? No, today, as ever before, metals are the key materials of construction.

Metals go to make the frames of multistorey buildings, the latticed arches of bridges spanning big rivers, the streamlined bodies of jet planes, and the cigar-shaped hulls of space rockets. Metals are the bedrock of present-day civilization. The demand for them grows as mankind climbs the ladder of progress.

In the early 19th century, or a mere hundred and fifty years ago, less than one kilogram of metals was produced for every man on the Earth. In 1800, for example, the world output of iron was less than 500 thousand tons. People lived in low wooden or brick buildings, rode in wooden carriages and hansoms, tilled the land with wooden ploughs, and wove fabric on wooden looms.

The past hundred and fifty years have seen unprecedented advances in science, technology and industry. A dense network of railways has been laid on the inhabited continents. A still denser network of power transmission, telegraph and telephone lines has been strung above.

With a halo of adventures around them, but slow and small, wooden ships have given way to veritable floating towns of steel. Cars, trolley-buses and motor coaches have ousted horses and mules. Man-made birds, each capable of lifting fifty tons or so of payload, have taken to the air. The wooden plough has been replaced by gang ploughs hauled by tractors whose steel cylinders pack the power of a herd of horses. Wooden looms can only be seen in museums. Man has sent his scouts to the Moon and has been to outer space himself.

All of this progress has become possible because the per capita production of metals is now over 150 kilograms, and the total quantity of metals in machines, structures and buildings is about 4,000 million tons. To date metals still remain the basis of technical progress.

What about the future? Will metals have to make room for other materials, such as plastics?

Man-made materials whose age is just beginning will probably replace metals in some uses. The chances are there will be plastic buses and ships, plastic planes and houses. But metals too will keep on improving, revealing more and more of their potentialities. Production of metals will keep

growing, and this growth will govern the progress of engineering and industry.

It would be wrong to set metals against plastics, steel hawsers against nylon cords. They are allies rather than rivals. A metal should be used where it can be used best; a man-made material should go where it is superior to metals. There will be enough room for all materials in science, engineering, industry and all other fields of human activities of the future. Much as today chemical equipment made of metals produces plastics, will metals and synthetic materials, the two basic types of materials in man's service, maintain a strong alliance in the future.

Today, however, technical progress is based on metals.

EIGHTY BROTHERS

The ancient Romans knew eight metals, gold, silver, copper, tin, lead iron, quicksilver and antimony. The Middle Ages brought with them the discovery of zinc, bismuth and arsenic. Together with antimony, however, they were generally classed as a separate group of semi-metals. They were hard to forge, and at that time malleability was looked upon as the basic indication of a metal. In 1763, the great Russian scientist Lomonosov could name only six metals. In addition to antimony, he also excluded quicksilver, although he was the first to prove that, when frozen, quicksilver could be forged. As he wrote in his "Fundamentals of Metallurgy, or the Mining Art", "A metal is a lustrous body that can be forged. We find six such bodies, gold, silver, copper, tin, iron and lead."

Towards the end of the 18th century chemists had identified about twenty metals, and by the time Mendeleyev came out with his Periodic System there were nearly fifty of them.

Today about eighty metals are known. Among them are the familiar iron, copper, aluminium, lead and tin; the noble metals such as gold, platinum and silver; artificial elements non-existent on the Earth, such as technecium, americium and curium; the rare metals yttrium, lanthanum, lutecium, thulium and erbium. I bet many of you have never heard of some of the metals in the last group.

Still, what are metals? Lomonosov wrote: "Metals are bodies which are hard, malleable and lustrous." Is this enough to tell a metal from a non-metal?

No, it is not. We list quicksilver as a metal, and no one has any doubt about it. At room temperature, however, quicksilver is a liquid. Crystals of iodine glitter much as those of the metal antimony. Many metals are inferior in ductility to, say, white phosphorus, a wax-like soft material.

PERIODIC TABLE OF THE ELEMENTS

Groups →	I	II	III	IV	V
2	6.939 **3** Li Lithium (1 2)	9.0122 **4** Be Beryllium (2 2)	**5** 10.811 B Boron (3 2)	**6** 12.01115 C Carbon (4 2)	**7** 14.0067 N Nitrogen (5 2)
3	22.9898 **11** Na Sodium (1 8 2)	24.312 **12** Mg Magnesium (2 8 2)	**13** 26.9815 Al Aluminium (3 8 2)	**14** 28.086 Si Silicon (4 8 2)	**15** 30.9738 P Phosphorus (5 8 2)
4	39.102 **19** K Potassium (1 8 8 2)	40.08 **20** Ca Calcium (2 8 8 2)	44.956 **21** Sc Scandium (2 9 8 2)	47.90 **22** Ti Titanium (2 10 8 2)	50.942 **23** V Vanadium (2 11 8 2)
	29 63.546 Cu Copper (1 18 8 2)	**30** 65.37 Zn Zinc (2 18 8 2)	**31** 69.72 Ga Gallium (3 18 8 2)	**32** 72.59 Ge Germanium (4 18 8 2)	**33** 74.9216 As Arsenic (5 18 8 2)
5	85.47 **37** Rb Rubidium (1 8 18 8 2)	87.62 **38** Sr Strontium (2 8 18 8 2)	88.905 **39** Y Yttrium (2 9 18 8 2)	91.22 **40** Zr Zirconium (2 10 18 8 2)	92.906 **41** Nb Niobium (1 12 18 8 2)
	47 107.868 Ag Silver (1 18 18 2)	**48** 112.40 Cd Cadmium (2 18 18 2)	**49** 114.82 In Indium (3 18 18 2)	**50** 118.69 Sn Tin (4 18 18 2)	**51** 121.75 Sb Antimony (5 18 18 2)
6	132.905 **55** Cs Cesium (1 8 18 18 8 2)	137.34 **56** Ba Barium (2 8 18 18 8 2)	138.91 **57** La Lanthanum (2 9 18 18 8 2)	178.49 **72** Hf Hafnium (2 10 32 18 8 2)	180.948 **73** Ta Tantalum (2 11 32 18 8 2)
	79 196.967 Au Gold (1 18 32 18 8 2)	**80** 200.59 Hg Mercury (2 18 32 18 8 2)	**81** 204.37 Tl Thallium (3 18 32 18 8 2)	**82** 207.19 Pb Lead (4 18 32 18 8 2)	**83** 208.980 Bi Bismuth (5 18 32 18 8 2)
7	[223] **87** Fr Francium (1 8 18 32 18 8 2)	[226] **88** Ra Radium (2 8 18 32 18 8 2)	[227] **89** Ac Actinium (2 9 18 32 18 8 2)	**104** Ku Kurchatovium (2 10 32 ...)	**105**

Between III and IV, group 6–7: 58–71 *, 90–103 **

140.12 **58** Ce Cerium (2 8 20 18 8 2)	140.907 **59** Pr Praseodymium (2 8 21 18 8 2)	144.24 **60** Nd Neodymium (2 8 22 18 8 2)	[145] **61** Pm Promethium (2 8 23 18 8 2)	150.35 **62** Sm Samarium (2 8 24 18 8 2)	151.96 **63** Eu Europium (2 8 25 18 8 2)	157.25 **64** Gd Gadolinium (2 9 25 18 8 2)

232.038 **90** Th Thorium (2 10 18 32 18 8 2)	[231] **91** Pa Protactinium (2 9 20 32 18 8 2)	238.03 **92** U Uranium (2 9 21 32 18 8 2)	[237] **93** Np Neptunium (2 9 22 32 18 8 2)	[242] **94** Pu Plutonium (2 9 23 32 18 8 2)	[243] **95** Am Americium (2 8 25 32 18 8 2)	[247] **96** Cm Curium (2 9 25 32 18 8 2)

Periodic Table (fragment)

	VII	VIII	Periods

Legend:
- He — s-elements
- Ne — p-elements
- Hg — d-elements
- Td — f-elements

VI			

1.00797 H 1 — Hydrogen, 1
4.0026 He 2 — Helium, 2 — Period 1

8 15.9994 O — Oxygen, 6 2
9 18.9984 F — Fluorine, 7 2
20.183 Ne 10 — Neon, 8 2 — Period 2

16 32.064 S — Sulphur, 6 8 2
17 35.453 Cl — Chlorine, 7 8 2
39.948 Ar 18 — Argon, 8 8 2 — Period 3

51.996 24 Cr — Chromium, 1 13 8 2
54.9380 25 Mn — Manganese, 2 13 8 2
26 55.847 Fe — Iron, 2 14 8 2
27 58.9332 Co — Cobalt, 2 15 8 2
28 58.71 Ni — Nickel, 2 16 8 2

34 78.96 Se — Selenium, 6 18 8 2
35 79.904 Br — Bromine, 7 18 8 2
83.80 Kr 36 — Krypton, 8 18 8 2 — Period 4

> Atomic weights and mass-numbers of longest-lived isotopes (in brackets) are International 1965 values

95.94 42 Mo — Molybdenum, 1 13 18 8 2
[99] 43 Tc — Technetium, 2 13 18 8 2
44 101.07 Ru — Ruthenium, 1 15 18 8 2
45 102.905 Rh — Rhenium, 1 16 18 8 2
46 106.4 Pd — Palladium, 18 18 8 2

52 127.60 Te — Tellurium, 6 18 18 8 2
53 126.9044 I — Iodine, 7 18 18 8 2
131.30 Xe 54 — Xenon, 8 18 18 8 2 — Period 5

183.85 74 W — Tungsten, 2 12 32 18 8 2
186.2 75 Re — Rhenium, 2 13 32 18 8 2
76 190.2 Os — Osmium, 2 14 32 18 8 2
77 192.2 Ir — Iridium, 2 15 32 18 8 2
78 195.09 Pt — Platinum, 1 17 32 18 8 2

84 [210] Po — Polonium, 6 16 32 18 8 2
85 [210] At — Astatine, 7 18 32 18 8 2
[222] Rn 86 — Radon, 8 18 32 18 8 2 — Period 6

106

Legend box:
Mass number of longest-lived isotope
Atomic number (number of electrons in atom)
Number of electrons in shell
84 [210] Po — 6 18 32 18 8 2
Atomic weight ($^{12}C=12$ scale)

158.924 65 Tb — Terbium, 2 8 27 8 2
162.50 66 Dy — Dysprosium, 2 8 28 8 2
164.930 67 Ho — Holmium, 2 8 29 8 2
167.26 68 Er — Erbium, 2 8 30 8 2
168.934 69 Tm — Thulium, 2 8 31 8 2
173.04 70 Yb — Ytterbium, 2 8 32 18 8 2
174.97 71 Lu — Lutetium, 2 9 32 18 8 2

[247] 97 Bk — Berkelium, 2 9 26 32 18 8 2
[249] 98 Cf — Californium, 2 9 27 32 18 8 2
[254] 99 Es — Einsteinium, 2 9 28 32 18 8 2
[253] 100 Fm — Fermium, 2 9 29 32 18 8 2
101 Md — Mendelevium, 2 9 30 32 18 8 2
102 (No) — Nobelium, 2 9 31 32 18 8 2
103 Lr — Lawrencium, 2 9 32 32 18 8 2

Today we identify elements as metals in the first place on the basis of several essential properties common to all of them. For all metals are good conductors of electricity and heat, display lustre and ductility; in chemical reactions they all behave in the same way.

However, it is the internal structure of elements that governs their properties. So metals must have something in common here.

Let us look into a metal through a microscope. The first to do this in Russia was the famous metallurgist Anosov in the 19th century.

If we look at an ordinary piece of metal though, such as the blade of a pen-knife, we shall only see a bright circle of light in the microscope. Polished metal reflects light almost equally in all directions. To make the internal structure of a metal visible, its surface must be etched with a diluted acid. The constituents of the metal differing in chemical and physical properties will be attacked by the acid differently, and a specific pattern will stand out in the microscope.

It is not an easy job to say what is what in that maze of light streaks and dark bands. However, scientists have successfully coped with the problem. The first thing they discovered was that all metals are crystalline.

As a matter of fact, the crystalline structure of many metals is visible to the naked eye. The reader has probably seen a fresh fracture of a steel or cast-iron article. Distinctly seen in the hills and hollows of the fracture are tiny crystals.

True, in the way they usually grow solid, metals have no time to form large and well-defined crystals. As soon as the liquid metal is poured into a mould, an enormous quantity of tiny crystals appear and make what is known as the skin of the ingot. Oriented in all directions, the crystals crowd one upon another, and their shape is distorted. As solidification goes on, columnar crystals, or dendrites, spread from the wall towards the centre where they heap up as spirit moves them. Heat treatment, rolling, hammering or pressing further deform, or refine, the crystals. Yet, as long as a metal is solid, it remains crystalline.

However, most solids in nature are also crystalline. So, this property cannot be alone responsible for what sets metals apart from other materials.

The fundamental cause of the common properties of metals has been discovered only recently, during the past few decades. The credit for the discovery is due to the physics of metals, a new science which came into being in the twenties.

In their study of the internal structure of metals, physicists have used the latest scientific tools such as X-ray structural analysis and the electron microscope. With them, they have been able to look into the crystals of metals and to get a more or less accurate knowledge about the metallic state of matter.

They have established that metals owe their properties, such as electrical and thermal conductivity, metallic lustre and, often, formability, to mobile, or "free", electrons which wander between the atoms of a metal. They have also discovered that the sites in the crystal lattice, usually held by atoms, are occupied by positive ions. Free electrons broken loose from their atoms are shared by several ions and thus hold them together. This is a metallic structure. Obviously, such a structure can be formed only in a material having outer electrons which can easily break loose from their atoms. Then the material is a metal.

Of course, sometimes electrons in a metal cannot break loose from their atoms to become free or roaming. Or it may so happen that materials which are not usually metals come by a metallic structure. Thus, in phosphorus under heavy pressure the atoms in its crystals are brought together, and some of the electrons become "common".

At one time scientists believed that the thin solid crust of the Earth floated on an ocean of molten plasma. Today, this view has been abandoned. Scientists have peeped into the Earth's insides and investigated the travel of elastic waves produced by earthquakes through the planet's body. From their observations they have learned that at a depth of 2300 kilometres the planet's material sharply changes in nature. It comes to have wholly different properties—those of metals. For this reason they believed for some time that the planet's core consisted of iron and nickel. They even quoted exact figures, 90.67 per cent (by weight) of iron and up to 8.5 per cent of nickel. The balance was given to cobalt, phosphorus, sulphur and some other elements.

In recent years, however, it has been shown that under the huge pressure of more than 1,500,000 atmospheres due to the heavy burden of the overlying rock, the atoms of any element are so compressed that it acquires the properties of metals that have been noted by scientists.

Today, speaking of the Earth's core, scientists no longer think of it as consisting of metals. Simply, it is in a peculiar state brought about by super-high pressure.

SIMILARITY AND DIFFERENCE

When, after the invention of the telescope, astronomers began to watch the planets of the solar system, they were amazed by the similarity of those celestial bodies to each other and to the Earth. Indeed, the planets proved to be the shape of a sphere, their axes of rotation to make an angle with the orbital plane, and most of them to have an atmosphere in which more or less dense clouds could sometimes be seen. And almost all of them were noticed to have seasons of the year, day and night.

Years passed. Man's knowledge of nature kept expanding. Gradually scientists came to be amazed by the differences between the celestial bodies.

Why is it that Venus is covered with such dense clouds that we cannot see its surface? Where has the Moon come by the strange circuses unknown on other planets? What are the "canals" on Mars? Why is it that, of all planets, only Saturn is girdled by a disk-like ring?

Today it is difficult to say what the nine planets of the solar system have more—similarity or differences.

The eighty metals differ as much. Take their melting points, for example. There is a metal which remains liquid at thirty degrees below zero. It freezes only when the temperature drops below —38.9°C. It was long before people realized that this metal, quicksilver, could be solid. It was not until 1759 that Braun of St. Petersburg, Russia, could freeze quicksilver by placing it in a cooling mixture of snow and concentrated nitric acid.

There is another metal which can be melted by the heat of your palm. It is cesium. It melts at 28.5°C.

Rubidium melts at 39°, sodium at 97.9°, tin at 231.8°, lead at 327°, zinc at 419°C. All of these metals can be melted over the flame of a gas range.

On the other hand, there are metals which are very difficult to melt. For centuries man failed to prepare iron from its ore for the simple reason that he could not reach its melting point, 1532°C.

Iron, however, is not the most difficult metal to melt. More than a thousand degrees above it are molybdenum, which melts at 2600°, and rhenium, which becomes liquid at 3000°C. This is only half as hot as it is on the surface of the Sun.

Yet the blue ribbon for refractoriness, as this property is called, goes to tungsten, which melts at 3410°!

So, the difference between the most fusible and the most refractory metals is 3450 degrees Centigrade. Yet, if we take a deeper look into the very process of melting, we shall find that metals have something in common.

For one thing, each of them melts at a certain definite temperature, because they are crystalline. Amorphous materials, such as tar or glass, first grow soft when heated and then melt, and you cannot draw a distinct demarkation line between the two states. For another, even when liquid, they have many properties in common. And the atoms in a molten metal are arranged exactly as they are in the solid state.

The same is true of other properties, such as thermal conductivity. Take a piece of wire, such as paper fasteners are made from, and put one end of it into the flame of a burning match. Soon you will feel the other end of the wire in your fingers become hot. Heat has travelled along the wire, but not along the match. You will not feel it hot until it has burned to the tips of your fingers. In other words, metal conducts heat well, and wood does not.

Engineers learned long ago how much heat is conducted through walls one metre thick every hour at a difference of one degree on either side of the wall. This ratio, known as the coefficient of thermal conductivity, shows how much heat the water in a steam boiler can get from burning fuel or how much heat will be lost through the walls of a house in winter. Let us have a look at the table of thermal conductivities of metals.

For silver, the coefficient of thermal conductivity is 360. This is the highest figure among the metals. Next comes copper with a thermal conductivity coefficient of 335. Gold has a thermal conductivity of 269, aluminium 180, tungsten 145. The poorest heat conductors among the metals are quicksilver (25), lead (30) and steel (39).

Among the non-metals, the best heat conductor is ice. Yes, ice. Its thermal conductivity is 1.9 and that of granite is 1.89. This is one-thirteenth of quicksilver's. Other non-metallic materials, such as paper, glass, plaster or brick, stand still lower in that respect. Below them are gases. The thermal conductivity of nitrogen, the main constituent of atmospheric air, is 0.02, and of the noble gas xenon 0.004.

Now you can easily guess why central-heating radiators, which should give up as much heat to the air in the homes as possible, are made of metal; why in regions with cold winters doors are covered with felt; why steam boilers are never made of reinforced concrete; and why curling-irons are fitted with wooden handles.

In the light of the present-day concepts about the internal structure of metals, we can easily explain why metals and non-metals differ so much in thermal conductivity. The point is that heat in metals is conducted not only due to the oscillations of the atoms in the crystal lattice, but also by free electrons. The lighter electrons are much easier to set in motion than the heavier atoms which, in addition, are bound to their sites in the lattice. So, the bulk of the heat in metals is carried over by electrons.

Speaking of the common properties of metals, we mentioned their high electrical conductivity. This means that they offer little resistance to the flow of a current through them.

A comparison will show that metals have a far greater electrical conductivity than non-metals or composite materials. The best conductors of electrical current are silver and copper. They are followed by gold, aluminium, and tungsten. Current runs into a higher resistance when it flows through iron and quicksilver.

If we arrange the metals in decreasing order of thermal conductivity, we shall find that their electrical conductivity decreases in almost the same sequence, for electric current is also a flow of electrons.

As the purity of a metal increases, its lattice becomes more perfect, and it conducts electric current better. On the other hand, minute amounts of impurities, or mechanical working that distorts the lattice, such as rolling,

reduce electrical conductivity. The ions are dislodged from their sites in the lattice and stand in the way of free electrons. The electrons run into the ions, give up to them some of their energy of motion, and bring about thermal agitation of the ions. The metal becomes heated —some of the electric current flowing through it is wasted as heat.

A rough idea of what happens in a metal can be got from this analogy. Picture to yourself a broad street lined with buildings on either side—they are like the ions in the lattices. Cars move in the street—they are like free electrons. Now suppose some of the buildings have been moved into the middle of the street—they are now like the atoms of impurities. The cars have to turn away and around them, and the traffic slows down, the same way as electrical conductivity decreases in an impure metal.

This is the reason why wires, cables and switch contacts are made from the purest copper. To make it, crude copper from smelteries is electrolytically refined. You may say it is "picked" atom by atom. Electrolytic copper, as it is called, contains not more than five parts of any impurities in ten thousand.

Silver is a still better conductor of electricity, but it is too costly to be made into wires for street lighting or electric trains. You can see silver conductors only in precise laboratory instruments and in important switches.

Where high resistance is essential, such as in the conversion of electricity into heat, you will find the alloys constantan and nichrome.

The electrical conductivity of metals changes with temperature in a peculiar way. As a rule, the resistance rises and falls with temperature. This is because the agitation of the ions in the lattice increases as the material is heated, and they offer a greater resistance to current flow.

In our "street" analogy, this may be likened to the buildings on either side moving into and out of the street continuously. Then only a narrow lane in the middle of the street would be left for traffic.

All of these things were not particularly hard to explain. But scientists ran into a real surprise when they measured the electrical resistance of metals at extremely low temperatures, near absolute zero. As the reader surely knows, the "absolute zero" is the lowest possible temperature, about —273°C, when theoretically all thermal motion of molecules ceases.

This was first noticed by the Dutch physicist H. Kammerlingh-Onnes in 1913 when he was measuring the electrical resistance of quicksilver at low temperatures. All of a sudden, when the temperature was but 4.12 degrees above absolute zero, the resistance of the frozen quicksilver dropped so low that the scientist just could not measure it.

The researcher improved his apparatus and carried out his experiment as carefully as he could. But the result was the same. The metal seemed to have lost all of its resistance. An electric current, once passed through

a ring of frozen quicksilver, kept flowing for an indefinitely long time without decreasing. For all his attempts, the scientist was unable to measure the resistance near absolute zero. Later this loss of all electrical resistance by metals was termed superconductivity.

To date, twenty-three pure metals, many alloys and chemical compounds have been added to quicksilver as superconductors. Each of them becomes superconductive at a definite temperature, called characteristic transition temperature. It is 1.14°K for aluminium ("K" stands for "Kelvin scale" the zero of which is absolute zero) 0.79°K for zinc, 7.26°K for lead, 4.3 for vanadium, 9.22°K for niobium. The highest transition temperature now known is near 18°K for Nb_3Sn, an alloy of niobium and tin.

Superconductivity remained unexplained for a long time. It was only recently that Nikolai Bogolyubov, a Fellow of the Soviet Academy of Sciences, offered a plausible theory.

MAGNETISM

A fairy tale of olden times tells about a tall magnetic rock standing somewhere in the ocean. Its pull is felt for hundreds of miles. The ships which happen to move within its reach are in for big trouble. They no longer answer the helm or sails and with ever increasing speed move towards the rock. With their chains unwound, the anchors fly ahead of the ships, held taut by an unseen but powerful force and pulling the ships along. The water holds back the ships, and the guns are torn off their carriages, the hulls are stripped of their plating, and the nails are pulled out of the boards. Like monstrous shells and bullets, they whiz through the air, pulled by the irresistible force of the black rock. This goes on for days. Stripped of their metal, the ships fall apart, and the sailors perish. Few survivors clinging to metal pieces reach the rock. It bristles with metal objects like a fir with needles. Nothing can grow on its iron top. And the people who have been lucky to escape drowning die of thirst and hunger.

Fortunately, no such rock exists or can exist on the Earth. Neither nature nor man can make a magnet that strong.

Yet, nature has produced a magnetic material which can attract iron pieces. It is lodestone, or magnetite. A lump of lodestone can attract nails and iron filings.

This property of lodestone was known to the ancients and amazed them greatly. Lucretius Carus, a philosopher and poet of ancient Rome, tells us about magnetic rings held under the dome of a temple by their mutual attraction alone. The remarkable force of magnetic attraction has always intrigued the inventors of perpetual-motion machines. Quite a number

of designs in which a magnet was to do the trick have been devised. They, however, have not saved man the trouble of building water and wind mills and of producing coal and petroleum.

Some other materials can also be made magnetic. When rubbed with a lump of lodestone, a strip of steel becomes magnetized. Now it, too, can attract metal objects. It also comes by another property. Suspended by a silk thread, one of its ends will always seek north.

About forty centuries ago, Chinese travellers and generals used magnetic figurines put up on carts. The spread arms of the figurines would always seek south, indicating the direction in the vast expanses of the Asian steppes and deserts. In the 3rd century A. D., the Chinese came to use a primitive compass—a steel strip suspended by a silk thread. The compass became known to the Europeans only around the 11th or 12th century. Since then, it has been helping sailors to find their direction in the sea.

What is magnetism? Do all of the metals possess it?

Yes, all metals can be magnetized, although to a different degree. This property is particularly strong in four pure metals, iron, cobalt, nickel and gadolinium. Gadolinium is a rare earth. In pure form, it can be prepared only in specially equipped chemical laboratories.

Many alloys of these metals, such as steel and cast iron, are also easy to magnetize and are all called ferromagnetic.

Aluminium, platinum, chromium, titanium and manganese are not so readily magnetized. Their magnetism can be detected only with very sensitive instruments. They are called paramagnetic.

Then there are diamagnetic metals, such as tin, lead, copper, silver and gold. They, too, can be magnetized, a little, but instead of being attracted to a magnet, they are repelled from it.

The cause of this difference in magnetic properties lies deep in the structure of metals, in their atoms.

In the early 19th century, Andre Marie Ampere, the outstanding French physicist and mathematician, came out with an explanation of magnetism. As he believed, inside iron there is a huge number of circular currents, or current loops. As long as there is no external magnetic or electromagnetic field around a piece of iron, these loops lie at random, and their magnetic fields cancel each other. In the presence of an external magnetic field, however, all the elementary loops arrange themselves in the same direction, their fields add together, and the iron becomes magnetic.

It may sound strange, but the French scientist who did not know a thing about the atomic structure has proved right. In his hypothesis he worked from the simple knowledge that an electromagnetic field is set up around a coil carrying an electric current. Today we know that an electric current is a flow of electrons. We also know that each atom consists of electrons moving in orbits around the nucleus and spinning each about its axis. So

the ultimate source of magnetic properties is the orbital motion of the electrons around the nucleus and the spin of the electron about its axis.

In diamagnetic materials, the magnetic fields of the electrons and nucleus cancel each other. Therefore, their atoms show no magnetic properties. But when they find themselves in a magnetic field, they become tiny magnets. The north pole of each of them comes against the north pole of the external magnet, and the material is repelled.

In paramagnetic and ferromagnetic materials the magnetic fields of the electrons and nucleus add together to produce a stronger common field. Each atom in them displays magnetism. In paramagnetic materials, however, the thermal motion of the atoms prevents them from arranging themselves all in the same direction, and their total magnetization is low.

In ferromagnetic materials crystals are believed to consist of many small regions, or domains, each of which behaves like a magnet. When a magnetizing force is applied to a ferromagnetic material, the domains gradually turn so that they all lie with their north poles in the same direction, and the material becomes strongly magnetized.

As a metal is raised in temperature, its magnetization decreases. This is because the thermal·motion dislodges the atomic magnets out of alignment. At a certain definite temperature, called the Curie point after the French scientist Pierre Curie, ferromagnetic materials cease to be magnetic.

Scientists have also noticed that most ferromagnetic materials, when a magnetizing force is applied to them, change somewhat both in size and shape. The property has been termed magnetostriction. Magnetostrictive materials display a reverse property, a change in the magnetization of a body under pressure.

There is one more point to mention—the relationship between the magnetic field and the field produced by a current flowing in a conductor. As scientists have learned, the magnetic field is a particular form of the electromagnetic field. They are closely related. A steel bar can be magnetized by placing it in an electromagnetic field. By cutting a magnetic field with a conductor, we shall induce an electric current in it.

We shall not go further into electromagnetism. That would take us too far from our objective.

FAMILIES OF METALS

In the Periodic System devised by the great Mendeleyev, each metal is given a separate place. Each occupies a square of its own and bears a specific number.

Mendeleyev's System is the best guide in the world of metals. Whichever square we may take, however rare or hard-to-find in nature a metal

may be, its number will reveal to us many of its "vital statistics". This is the same as if we were to learn a man's age, occupation or other facts in "Who's Who" by his name.

We shall often turn to this "directory" of the elements. But to us, interested not so much in the metals themselves as in what they give or can give to man, it would be unreasonable to examine all the metals in turn. Instead we shall begin with the metals most important to man today. So, ours will be a different classification. Though not so strictly scientific as Mendeleyev's Table, it will serve our purpose better.

To begin with, we shall divide the metals into two unequal groups, ferrous and non-ferrous.

The ferrous group contains iron and its many alloys. That is an unequal division, indeed—one against seventy-nine. But in man's life, iron is perhaps as important as the rest of the metals taken together. As a matter of record, iron accounts for about 94 per cent (by weight) of all the metals produced in the world today. This is an impressive figure!

By separating iron and its relatives from the mighty clan of metals, we have done much. Yet, it is not at all easy to class the non-ferrous metals and their alloys. (Incidentally, in Russian they are called "coloured metals" which is true; lead is bluish-grey, gold is yellow, copper is red, nickel is white, and so on.)

The non-ferrous metals may be classed into heavy and light. Either group includes metals both very important to man and little used, if at all, today.

The heavy metals are copper, nickel, lead, tin, zinc, chromium, manganese and other metals with a specific gravity of more than five.

The light metals, of which there are thirteen, include sodium, potassium, beryllium, magnesium, calcium, strontium, aluminium and titanium.

Very often the non-ferrous metals are broken down into smaller families. Among the heavy metals are the noble metals, gold, silver, platinum, osmium, iridium, palladium, ruthenium and rhodium. They are all very stable chemically, resist corrosion and attack by most acids.

Sometimes, a group of trace metals is singled out. They have no ores of their own and are scattered throughout the Earth's crust. These are lithium, rubidium, yttrium, cesium, germanium, radium and many others. They are usually recovered from the ores of other metals in which they are associates.

The metals may also be grouped as rare earths, radioactive metals, and transuranic metals. We shall run into them more than once in the book.

Man seldom has to deal with pure metals. More often they come his way as a variety of alloys. What we call iron is, as a rule, an alloy of iron, carbon and some other elements. Sometimes what many call "copper" (ex-

cept copper wire) turns out to be either bronze or brass, i.e., alloys of copper and tin or zinc. Even gold in jewelry carries an addition of silver or copper.

This is not only because pure metals are difficult to prepare. As often as not they are less useful to man than their alloys.

ALLOYS

Mix buckwheat and rice. You will easily see and separate the individual grains of each in the mixture. This is a mechanical mixture.

Take a pinch of table salt. Chemists have long since found that it consists of the chemical elements sodium and chlorine. But the most powerful microscope will fail to tell the metal sodium from the gas chlorine. In a crystal of salt each atom of chlorine is combined with an atom of sodium. This is a chemical compound.

Put a spoonful of sugar into a glass of water and stir it. The sugar will dissolve, leaving not a single grain to see, even in a microscope. The molecules of sugar have become lost among the molecules of water. This is a solution.

And what is an alloy?

If you put this question to a metallurgist, he will answer with a question:

"Just what alloy have you in mind? Which elements make it up and in what amounts?"

He even may ask how the alloy has been produced. For alloys may be either mechanical mixtures, or chemical compounds, or solutions.

In their studies, metallurgists melted antimony and lead, poured the two melts together while stirring them thoroughly. The alloy was allowed to grow solid, and a specimen of it was placed under a microscope. The investigators could see a fanciful pattern of tiny crystals. Some of them were antimony, others were lead. That was a typical mixture of two metals. Mechanical mixtures also come out of alloying aluminium with silicon, bismuth with cadmium, and so on.

Scientists have noticed that such alloys, or mechanical mixtures, have a melting point which changes with the percentage of the constituents. But it is always below that of the most refractory of the constituents. A mixture which has the lowest melting point than the other alloys that can be made from the same constituents is called the eutectic.

Alloys of the mixture type have found many uses in engineering. As they are made up of crystals which differ in physical properties, it is possible to obtain what would seem unbelievable combinations of valuable properties by suitably proportioning the constituents.

Take bearing metals as an example. They are mechanical mixtures of lead, tin, copper and antimony. Embedded in a soft and pliable base,

or matrix, of lead and tin are crystals of antimony, hard and resistant to wear. Bearings lined with such an alloy have a long service life, a low coefficient of friction and such weirdly sounding properties as embedability (ability to embed in themselves foreign particles) and conformability (ability to deform plastically to make up for irregularities in bearing assembly).

Many metals can dissolve in other metals in any proportion. Copper can take in any amount of nickel, and aluminium any amount of magnesium. Some metals can dissolve in each other but little. Lead dissolves in zinc with difficulty. If we mix molten zinc and lead they will soon separate into two layers. The top layer will be zinc with some lead dissolved in it; the bottom layer will be lead with some zinc in solution.

To get to the root of the matter, let us look into the crystal lattice of alloys.

When an alloy is liquid, the molecules of one metal move among those of the other moving at random. When the alloy begins to solidify, the atoms make up crystals. It may so happen that a few atoms of the dissolved metal take the place of some atoms of the solvent in the newly formed crystal lattice.

This, however, occurs only when the atoms of both metals are of about the same size, differing by not more than one-seventh in diameter. These are alloys or solid solutions by substitution. Metallurgists today know quite a number of such alloys. Among them are alloys of iron, chromium and nickel; of cobalt and iron; of copper and nickel.

What we call "nickel" coins are made from a solution of copper in nickel. Copper is added in order to reduce the wear of the coins. "Copper" coins are made from a solid solution of aluminium in copper. This alloy is of higher quality than pure copper.

When a substance with small atoms dissolves in a metal with bigger atoms, they go into interstices in the crystal lattice, much as quite a number of ping-pong balls can be stowed between large footballs in a box. Such alloys are called interstitial solutions. A solution of nitrogen in iron is an example.

Sometimes the constituents of an alloy combine chemically. Carbon and tungsten combine to form tungsten carbide, which has its own chemical and physical properties. Its crystals make a mechanical mixture with the other components of the alloy.

Thus, one and the same alloy may be a combination of a mechanical mixture, a solution of one constituent in another, and their chemical compound. The actual form of an alloy, apart from its composition, depends on the manner in which it has crystallized, the type of heat treatment it has been given, and so on.

This is why an expert would not answer the question "What is an alloy?" at once and would ask for some more information.

Engineering today uses a great variety of alloys. Thus, as noted earlier, what we call iron and steel in everyday usage are alloys of iron and carbon. Bronzes are alloys of copper and tin or aluminium or lead. Brasses are alloys of copper and zinc. Cemented or sintered carbides made into high-speed cutting tools are also alloys of carbon, tungsten and titanium. The heater in your electric range is an alloy of nickel and chromium.

Like metals, alloys are often classed into specific groups. Thus we have light-weight alloys, bearing alloys, magnetic alloys, type metals, electric-resistance alloys, and so on. We shall deal with many of them more than once yet. Now let us turn to pure metals.

BANISHING THE IMPURITIES

One might think the metals which have given life to a huge multitude of alloys are useless to man in pure form. For even primitive metal-makers preferred copper-tin alloys to pure copper and tin. However, this is not so.

About fifteen years ago people knew only commercially pure metals with fifty to five parts of impurities in ten thousand, and chemically pure metals with not over one part of impurities in a hundred thousand. These figures, however, did not take into account the gases dissolved in a metal. Scientists had a very scanty idea about the far-reaching effect of minute amounts of impurities on some of the properties of metals, nor did they realize how a dissolved gas could affect the quality of a metal. In other words, they did not suspect metals could be made very pure.

Very pure metals came to the fore with progress in the new divisions of technology, such as nuclear power, semiconductors, heat-resistant materials.

When the nucleus of a uranium atom splits or, as physicists put it, undergoes fission, it shoots two neutrons, two projectiles capable of causing the fission of two more nuclei of uranium. But if the uranium fuel has the impurities boron and lithium, some of the neutrons will be captured by their nuclei, and the reaction will stop.

"We need uranium in which there is not more than one part of boron in a million", say the engineers designing nuclear power plants.

"We need germanium in which there is not more than one part of copper in ten million", say the physicists working on semiconductor devices. "In fact, any impurities are undesirable. The germanium we need must have not more than one part of impurities in ten million".

Today such very pure metals are being produced commercially. Working more and more with them, scientists and engineers are learning more

about their miraculous properties. They have learned that many very pure metals have better plasticity, resistance to corrosion and heat, and electrical conductivity. Aluminium of high purity is as soft as lead. Freed from impurities, titanium, which has always been regarded as brittle, can be easily rolled into sheets and strip. On the other hand, even the slightest traces of impurities may ruin some of the very important properties of metals.

Today, the drive for pure metals is in full swing. It began in the laboratories and studies of scientists, then it was moved into pilot plants, and now it is being carried on at factories.

The technology of very pure metals has raised quite a number of problems. One of them is how to determine the purity of a metal. Chemical analysis is too crude. To determine as little of an impurity as one part in a hundred million in a very pure grade of germanium by methods of chemical analysis is the same as to try and cut out a mosquito's eye with a chopper. Even spectral analysis, once thought of as fantastically sensitive, fails when it comes to the highest standards of purity. Fundamentally new techniques have had to be devised.

One method is to irradiate a specimen of a very pure metal with neutrons. The impurity atoms become radioactive, and their radioactivity gives a measure of their content.

The amount of impurities can also be determined from the properties of the metal sought, say germanium. If it meets the specified requirements it has been cleaned properly, and the proportion of impurities has been squeezed into the fixed limits.

Quite a number of tricks have been devised to prepare pure metals. The source materials are thoroughly cleaned, the charge is melted in a vacuum, the molten metal is kept away from contact with the walls and lining of the furnace, and so on.

A whole range of processes are used to banish the last traces of impurities from the metal. Here is how zirconium and titanium of high purity are obtained.

The apparatus, or reactor, used for the purpose is a large metal barrel with a metal lid. The joint between them is made tight by a seal. Passing through the lid and into the barrel are electric leads connected by a filament, and a device to lower and break a bulb of iodine inside the reactor.

The reactor is charged with titanium or zirconium sponge of commercial purity, and the lid is clamped down. Then a very deep vacuum (0.00001 atmosphere) is built up in the reactor, and the bulb of iodine is broken inside it. Highly aggressive, the iodine vapours react with the charge to form so-called iodides. The reactor is so heated that the iodides evaporate. At the same time the filament made from the same pure metal as being sought is heated to 1300-1400°C. At this temperature, the iodides decompose on com-

ing in contact with the filament, and the pure metal is deposited on it. The gaseous iodine can then react with the remaining sponge.

As the deposit of pure metal builds up, the filament gradually becomes a rod of considerable thickness. Then the reactor is allowed to cool and the iodine vapours to lodge on the walls, and the rod of very pure metal is withdrawn from the reactor.

Highly pure germanium is prepared by pulling crystals from a suitable solution. The method, known as fractional crystallization, uses the property of impurities to dissolve more readily either in the solid or in the liquid metal. Then, during solidification, they are either thrown out of the crystal and the portion of the melt to freeze last carries the bulk of the impurities, or pulled out into the crystal and the remaining portion of the melt contains very little of the impurities. Ordinarily, however, because of the diffusion that follows solidification, the impurities spread more or less evenly throughout the metal.

So, for the method to work, crystals must be removed continuously, as soon as they form, and the remaining melt must also be stirred continuously. In practice this is done thus. A charge of molten germanium of commercial purity is poured into a cell, and the seed, a germanium crystal attached to a rod, is dipped into the bath. As more pure germanium is deposited on the seed, the rod is withdrawn from the bath. The rod is rotated all the time so as to stir the melt and to drive the impurities thrown out by the crystals from the region of crystallization. Everything is done either in a vacuum or in an inert gas.

That is, of course, only an outline of the process. The actual procedure is far more complicated. With silicon, for example, the charge before melting is washed in water distilled twice. The melting is done in an atmosphere of hydrogen. Since the hydrogen, too, may carry some impurities, it is passed through a bed of activated carbon. For greater efficiency, the activated carbon is cooled with liquid nitrogen. A thousand and one other precautions are taken to keep even a speck of dust away from the metal. For as little as one part of copper in a million million will immediately tell on the quality of germanium. This impurity sometimes comes from the pure antimony added to pure germanium to improve its quality. And the addition of antimony is as small as one part in a hundred million!

PURE ANTIMONY

To me, my first encounter with antimony will remain also an encounter with the people who mine it among the wild Kirghizian mountains, on the outskirts of the country. So, I hope, the reader will bear no grudge on me if in this story of pure metals I include a few lines about the man whose

life is inseparable from the Soviet non-ferrous industry, although his name is not mentioned in encyclopaedias or glorified by poets.

We had just come back from the mine cut in a mountain nearby. It was there they were mining antimony, an element which is not so abundant in the Earth's crust. Then we saw how the ore was dressed into a concentrate by crushing, grinding in ball mills, and separation from the waste, or the gangue. It was in the concentration department we met Fyodor Alexandrov.

A few minutes later we found ourselves in the small room of the factory's engineer on duty. Sitting in front of us was a middle-aged man with a youth's vivid eyes and a finely cut face sun-tanned as anyone's there. He told us his life story, remarkable and, at the same time, ordinary for a working man of his generation.

Quite a few things had happened to him since 1931, when he came here with the first party of workers and engineers to build a mine and a factory in this valley squeezed in by mountains from all sides.

"It was more than a quarter-century ago," said Alexandrov. "But the sight I saw then is still fresh in my memory to the last detail. As today, the river was rumbling by, the mountains were green with grass, and the blue sky arched above. But there was not a single hut where the settlement stands now."

We looked out of the window and saw two- and three-storey buildings, tree-lined streets and, of course, the gloomy mountains as an inevitable background.

"We lived in tents and dugouts. Never parted with arms. Today you've passed the place where we routed the last Basmach band. We picked up a whole collection of foreign arms then. That was in 1933.

"A few months later we produced the first batch of antimony. That was done in a very primitive way. The metal was melted in clay pots, each holding three to five kilograms, in furnaces we had built with our own hands. Then, we began to build an ore-dressing factory. At the same time we were learning how to run it when it was completed. It took us three years, from 1935 till 1937, to complete the course of instruction without leaving our jobs. In 1938 I was appointed a foreman at the factory, although that was a job for an engineer. In 1942, I volunteered for the Army.

"After the war I came back here. I simply could not live without the factory. I left it again only once in 1952, when I went to Czechoslovakia to advise my colleagues there on the dressing of non-ferrous ores. By way of comradely assistance between friendly countries.

"Throughout these years, which have taken in so much, the mine, the ore-dressing factory and the smeltery have been growing and expanding before my eyes. Today, they are modern enterprises equipped with up-to-date plant."

Alexandrov took us through all the departments. In one of them we saw rows of huge metal cylinders. In them antimony was leached from its ore. There was nobody to be seen in the department; all operations were controlled automatically, from a control board.

In the next department, the pulp from the leaching operation was filtered to remove the waste, or cake, from it. This was done in big rotary disk filters, drum-shaped tanks, each divided into compartments by disks rotating on a common shaft. The pulp was drawn into the tanks through perforations in their walls by the vacuum built up inside.

"There is one thing I'd like to tell you about," said Alexandrov. "Look at that tube sprinkling the cake on the disks with water. It has been suggested by Pavel Baiborodov, a 27-year-old engineer. This may seem a trifle, but it has improved the separation of the waste. This saves thousands of roubles a year. It's not bad, is it?"

From the filters, the clarified solution went to the electrolysis department. In large cells, electric current picked atoms of antimony from the solution, or electrolyte, to deposit them at the cathode. I had expected to see a mirror-polished, bright surface. Electrolytic antimony turned out to be a brittle substance, dark-brown in colour, like solid lava. It was stripped off the cathode on a special machine and sent to reverberatory furnaces for smelting.

Electric hoists dropped the cathode antimony into a furnace. In the meantime, a special slag was prepared in another furnace nearby. When the time came to tap the molten antimony from its furnace, the casting conveyor, an endless line of metal moulds, was started up. Some molten slag was first poured into each mould, and then the molten antimony was run into them. The metal squeezed the slag, and it enveloped each slab, protecting it from oxidation by atmospheric oxygen. And so the slabs came off the conveyor in jackets of glassy slag. After it had been broken off, we saw glittering antimony cast in slabs, each weighing twenty kilograms.

Antimony was known in ancient Babylon where it was made into vessels and ornaments. Since then man has learned to use other metals for this purpose. However, engineering today has not rejected antimony. It is added to type metal with which this book has been printed, to the bearings used in a multitude of machines. An addition of antimony to many metals gives them greater hardness and protection from oxidation.

Wide use is also made of diverse chemical compounds of antimony with oxygen, chlorine, sulphur, and other elements. Most of the antimony produced a few years ago was not particularly pure. It was only recently that progress in semiconductor engineering called for highly pure antimony, having one atom of an impurity in tens or even hundreds of thousands of antimony atoms. Such is the purity of the antimony produced in the heart

of Central Asia, a purity which would seem attainable only in a research laboratory.

To make it pure, slab antimony is distilled in electric furnaces, and the antimony vapours are caught as a fine white powder, or antimony dioxide, in condensers. The powder is flushed with hydrochloric acid which ruthlessly destroys any impurities, however insignificant they may be. Then the powder is washed with distilled water to remove all traces of acid. It takes three hundred and fifty litres of water to wash off the acid from one kilogram of antimony dioxide powder.

The purified powder is smelted in electric furnaces to antimony metal. The metal is again distilled, flushed with acid, washed with distilled water, smelted to metal, and again distilled. This is repeated several times.

Finally the bars of antimony, thin and long like pencils, are placed in graphite boats and charged into a quartz tube for zone refining. An induction heater the shape of a ring is moved over and along the tube filled with argon, an inert gas. As it moves, the heater melts the antimony bar within a narrow zone. Outside such a zone, the metal grows solid as soon as the heater has moved farther on.

"By a physical law, when a substance crystallizes out of a melt, the impurities remain in the liquid phase," we learned from the engineer. "The same is true of antimony. From each zone the impurities are driven off towards one end of the bar. Moving the heater from end to end many times produces a bar of highly pure antimony, with all the impurities concentrated at one end. The end is broken off and re-smelted."

Lying before me on my writing table is a tiny piece of metal antimony: Its sharply broken faces glitter like mirrors. This is a reminder of the people who make the metal in the distant Kirghizian mountains for physicists and engineers.

OUTSIDE THE PERIODIC TABLE

When Mendeleyev formulated his Periodic Law and drew up his Periodic Table, some of the squares in the Table were left vacant. At his time, only sixty-three elements were known.

However, the vacant spaces did not remain so for long. In 1875, gallium was discovered. In 1879 it was followed by scandium and in 1886 by germanium. The existence and properties of the three had been predicted by Mendeleyev. Then there followed the discovery of rhenium, polonium, radium and others, some of which had also been predicted by Mendeleyev. One by one, the inert gases argon, helium, krypton, neon, xenon and, eventually, radon filled some of the gaps in the Table, and so did the rare earths.

In 1937, technetium, the first radioactive element to be produced artificially and predicted as eka-manganese by Mendeleyev, came along. Finally, francium, a very unstable element, was prepared in 1939 to fill the last vacant space in the Periodic Table.

However, in the years that followed it looked as if physicists had set their sights on extending the Table to include ever heavier elements. So came about elements of atomic numbers 93 (neptunium), 94 (plutonium), and 95 (americium). Today the Table ends with element 104, identified in 1964.

Can it be extended still farther? Can nuclear laboratories prepare more new metals with remarkable properties?

Most scientists believe that the life-times of further transuranium elements will become ever shorter as their atomic numbers grow. Some, however, hold a different view. The instability of elements does not increase continuously with increasing atomic number, they say. Technetium, far from the end of the Table, is unstable. But it is followed by stable elements. The atoms whose nuclei consist of 20, 50, 82 and 126 nuclear particles are very stable, and this is no coincidence. So it is not at all unlikely that the unstable transuranium elements will be followed by those with atomic numbers which will continue the numerical series for the stable elements.

We can hardly add anything to this now. Experiments or theoretical studies will prove or disprove either of the views. In any case, the limits of the Table have not yet been sounded.

What about extending it in the opposite direction, towards ever lighter elements?

In his sci-fic novel "The Black Stars", the Soviet writer Savchenko tells about a team of engineers working on a new element neutronium. It consists only of neutrons and occupies the first square in the Periodic Table. Finally, they do get the element. As it turns out, it possesses fantastic strength, thermal capacity, thermal conductivity, electric strength, and so on.

Without going into detail, if this element is ever obtained, it will have none of these fantastic properties. For one thing, the neutron is not stable. Its half-life in the free state is but slightly more than twelve minutes. How can we expect it to have super-strength or super-resistance to heat?

What if we move still farther, into the realm of negative atomic numbers?

There is a body of opinion that the Periodic Table can be extended into the region of negative atomic numbers. As physicists have shown, for every elementary particle there exists its mirror image, an anti-particle. Anti-particles may form anti-nuclei with negative charge and anti-atoms with positive elementary particles going around the nuclei in external orbits. These anti-atoms can make up molecules and crystals of anti-matter.

That anti-matter can exist is beyond any doubt to most physicists. Of course, it is any one's guess yet what properties anti-matter may have.

Such are our chances to extend the range of the metals we know today. As you can see, these chances are not many. It is not unlikely that man will have to content himself with these eighty "brothers" for a long time to come yet. The transuranium metals, the neutronium of science fiction and the metals consisting of anti-matter will remain where they belong —research laboratories or sci-fic novels—for long. However, you may be sure that as soon as man learns how to prepare any of the still unknown metals, he will surely get it. For man can accomplish anything.

CHARACTERS AND DESTINIES

I have before me the Periodic Table. The symbols of the metals are marked with circles in red pencil. I look at their Latin names. To me, they are almost living things, each with a character of its own, each with its own destiny, each with its own part to play in man's life.

Gold, yellow and soft, was the first metal to get in man's hands. Just where this happened we can only guess. It may have occurred on the banks of the slow Chinese rivers, or in the tropical jungles of Africa, or at the black-red rocks of Atlantis. Most probably, however, this took place in all of these places, or wherever man came.

Man could find native gold in the stony shoals of rivers while looking for flint to be made into arrowheads and axes. However, gold did not become man's helper. Man needed a staunch and reliable ally whose loyalty he could rely on. That would be too much for the soft and pliable gold. It fell to its lot to become coins, to glitter as the ornaments of women. Today, it is the international monetary standard. Scientists, too, have found some uses for gold in their laboratories.

Ringing bronze was the first alloy to serve man faithfully. It was made into hoes, spades, axes, spearheads and swords. That was the metal of toil and battles, the first metal to give its name to a whole period in man's history.

Yet, bronze proved a weakling. It could not even oust stone. Bronze and stone axes, bronze and bone arrowheads lived side by side. When man had learned how to make iron, a far stronger metal, bronze surrendered to it without practically any resistance.

When we say "iron" we cannot but feel respect for this powerful metal. Leaning upon the stick of iron, man rose to his feet to become a giant. The steps of iron have led him to his present-day majesty. If it were not iron, man would not have been able to tame fire and steam, to generate energy,

or to make aluminium and titanium, the metals of today. If it were not iron, man would not have been able to venture on the leap into the future in which we, the people of an age of rapid technological progress, all take part.

Historians do not extend the Iron Age to include our time. They stop somewhere before the present era. But even today iron is the basis of civilization. It will be very long before it resigns.

In my mind's eye I see iron as a powerful king, with its throne among hearths and forges, cheerful hammermen and sharp-tongued smiths. From the place where birth is given to ploughshares and scythes, steam-engine cylinders and rails, the guns of warriors and the harpoons of whalers, it holds its sway over the world. Today, this is perhaps an antiquated picture, and the royal chambers of iron have moved to blast furnaces and rolling mills—I won't argue. However today iron is not the sole master it was in the past.

Next comes aluminium, a silvery-white metal with a thin, dull coat of oxide, both ubiquitous and hard to get. In pure form, it was first prepared just a bit more than a century ago. At first it was made into useless ornaments. But a deft worker and a daring explorer, it has not put up with this lot. Though not so strong as iron, it is much lighter. In company with magnesium, it goes to make planes, space rockets and sputniks. To the heavy-footed and earth-bound iron such stunts are far more than it can do. Many more exploits can be expected of this young and daring metal. It is a good helper, just of the same temper as 20th-century man, inquisitive, clever and dashing.

Now we come to titanium. Taken from ancient myths, the name has stuck to the metal as if made to order. For some time, it kept modestly in the background. It did not hurry to butt in with its merits uninvited. About the same thing happens when a new teacher comes in the class. A forest of hands rises to his questions, and only one pupil sits quietly, silent most of the time. "He knows little, apparently," the teacher thinks. But when his turn comes to go to the blackboard, the pupil proves best. The same thing has happened to titanium. It has proved the best among its eighty brothers. Today it is looked upon as the rival of iron. Why, it has everything to become the main metal for man.

Eighty metals, eighty destinies, eighty characters.

We knew but little about germanium some twenty years ago. Today it is the basis of a technical revolution in whole divisions of engineering and industry.

Once uranium was mined in negligible quantities and used to make high-quality paints. This was so until man discovered huge reserves of power deep in its atoms. Today on it are pivoted man's hopes and fears, for it is equally powerful in work and murder. We must join our hands

to make it work and not kill. It must become a metal of power stations, and not one of battlefields.

There are other metals. It does not matter that not all of them have given or are giving their names to stages in man's history and that the contributions of some of them have been not so great. Nearly all of them are serving man. It may so happen that, instead of aluminium or manganese, titanium or zirconium, uranium or germanium, some other metals now modestly keeping quiet will help man to make great discoveries.

Metals are not simply bright crystals of certain properties. They embody the work of those who first prepare them in the fire of hearths or with the invisible discharges of electrolysis cells. They embody the work of people toiling at blast furnaces, in mines or ore-dressing plants. They embody the work of those who turn ingots into clever things serving us in our homes, in the street, in the factory. Quite a number of people have their destinies tied to metals.

There is even more than that to metals. Metals have been very important to the destinies of whole nations, countries and continents. The natives of America who knew only stone and bronze were a poor match for the conquerors clad in iron armour. Africans had learned how to make iron before Europeans, but they did not go farther than their primitive forge. And so, the African continent fell under the cast-iron heel of colonizers. The first world war, which engulfed in its flames the whole globe and took a toll of millions of lives, broke out, among other things, because of the iron ores of Lorraine. The controversy about who were to have them, the capitalists of Germany or the bankers of France, was carried into battlefields to be settled by blood and bullets.

To any developed country, metals are the basis of the national economy. Metals go to make tractors and harvesters, oil derricks and turbines, power transmission lines, Diesel locomotives and rails, streamlined planes and Martian probes, the components of TV receivers and the dashing arches of bridges, spanning canyons, the tireless movement of your watch and big rolling mills.

Out of the host of things about metals, we shall only take up those which can tell us how man makes and uses metals, how man has conquered and rules them.

2

FROM THE PLANET'S TREASURY
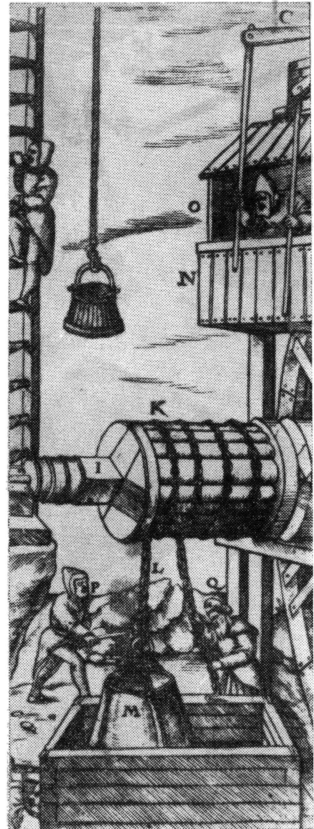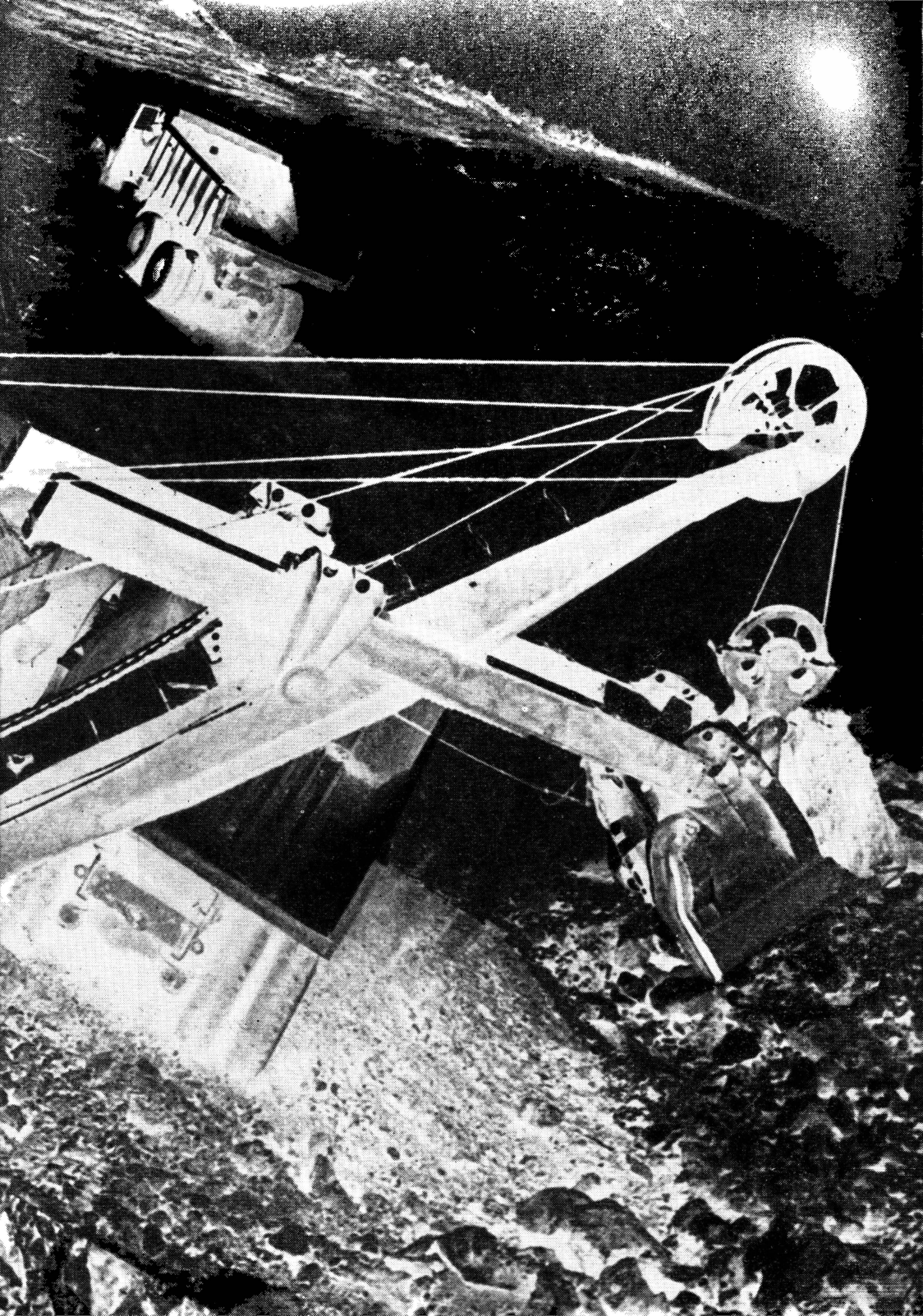
The oval brown lumps, looking like frozen bubbles of dirty foam, are goethite, one of the iron ores in the limonite group.

The dark-grey lumps with a violet tint, glittering at a fresh fracture, are galena, an ore of lead.

The red rock, as if stained with blood, is cinnabar, the ore of mercury.

The sulphur-yellow streaks in granite are pitchblende, an ore of uranium.

The dark-green rock, fluffy to the eye, is malachite, an ore of copper.

The transparent crystals, green, sky- and sea-blue, grown together at the base into a grainy whitish-green mass, are aquamarine, one of the species of beryl, the only ore of beryllium.

The ores of metals, those treasures of the Earth, are perhaps more diverse than the metals themselves. Looking for them, man has climbed to the tops of mountains and sunk mile-deep shafts into the Earth's insides. He has built towns in deserts and tropical jungles only because Nature has hidden one of its treasures there. But the Earth's bowls are not the only, although the main, source of metals. Man catches them in the hot water of geysers, extracts them from seaweeds, produces them from sea water and lifts them from the sea bottom. He would take them from air, if it

contained any. Sometimes man has to put in a good deal of effort to get metals.

Nature has not prepared pure metals or well-proportioned alloys for man. Loaves of bread have never grown on trees. It is with his penetrating mind that man sees these hidden treasures in the stone pyramids of mountains and under the carpet of velvety grass, in the placers of rapid rivers and on the bottom of seas. It is with his toiling hands that man breaks up the stone armour to get into Nature's vaults. As often as not, the road from mine to metal is both thorny and long. Sometimes, this is not a metal but an ore concentrate that man first gets to melt into metal.

As a ray comes from light, so metals come from ores. Speaking of metals, we cannot forget about ores.

THE BIRTH OF ORES

As Otto Schmidt, a Soviet scientist, pictures this for us in his hypothesis, everything started with the heating of the Earth after it had formed from a cloud of gas and dust. The cloud carried quite a lot of the radioactive elements uranium, radium and thorium. In the planet's insides, the energy they gave up turned to heat. Where the accumulations of radioactive elements were especially big, molten rock made underground lakes. The heat expansion and shifts of rock in the inside changed the Earth's surface. Mountains (of which not a single trace has been left now) would rise, depressions form, and volcanos erupt. Whole continents would come and go. That was the stormy childhood of the planet. This was because the planet carried much more radioactive materials than it does today. According to the Soviet scientist Khlopin, the total amount of radioactive elements in the Earth some 2,000 to 2,500 million years ago was three or four times as large as it is now.

The molten rock in the underground lakes, or magma, carries all the chemical elements that make up the Earth's crust. True, the composition of magma varies from place to place. What we have in mind is its average composition. From magma have come many ores of metals.

When a volcano erupts, a black cloud of vapours, smoke and ash covers the sky. A glow of fire blazes above the top of the mountain. Peals of thunder follow one another. The ground trembles under your feet. Then a fiery stream gushes out of the crater. It flows down the sides of the volcano, burning all that stands in its way. This is lava.

A solid crust forms on it at once. But more lava pours out, breaking up and swallowing the crust. In this way, the lava is stirred many times before it finally solidifies into a dark-grey or black sheet of effusive rocks.

Lava carries all the metals man needs, exactly as granite and basalt do. The continuous stirring and rapid cooling of lava, however, do not allow the metals it carries to group and separate themselves out of it. Therefore, lava may be a source of ores but seldom.

But it is not always that magma manages to break outside from the underground lakes of molten rock. Very often it can move only half way up. Then its huge intrusions freeze inside the Earth's crust, surrounded by the cooler solid rocks. It takes the magma intrusions centuries and even millenia to cool completely. Most of the ore deposits have been formed that way.

. As the molten magma cools, the sulphur compounds of iron, nickel and copper are thrown out of solution first. They are heavier than the remaining melt and sink to the bottom. That is how many of the known deposits of nickel and copper ores were formed.

The magma cools slowly, and more of its constituents separate out of solution. Finally, the bulk of the melt freezes, but it still holds a liquid fraction. The liquid is squeezed out of the solidified rock into the cracks made by the powerful underground forces in the Earth's crust to solidify there, forming ore veins of titanium, chromium and iron.

The solidifying magma also gives off a huge amount of still more penetrating vapours and fumes. On cooling, they throw out crystals of a great variety of precious and semiprecious stones from rock crystal to emeralds vying with diamonds in value. They form crystalline rocks, or pegmatites. In addition to gems, such veins carry the ores of the rare and valuable metals beryllium, niobium, tantalum, lithium, and cerium.

Where the solidifying magma comes in contact with adjoining rocks, ores are formed by a still more complicated action. The rocks are partially dissolved in the magma and go into chemical reactions with it. As a rule, deposits of iron, tungsten, bismuth, copper and gold are found at and near the surface of contact.

Still other companions of the solidifying magma are enormous quantities of gases and water vapour. They, too, carry dissolved elements in great numbers. As they reach cracks in the rocks, the gases and vapour condense, and the dissolved elements separate. The ore deposits they form are called hydrothermal.

Hydrothermal deposits hold a broad range of metals, such as tin, tungsten, molybdenum, lithium, arsenic, bismuth, silver, copper, zinc, lead, cobalt, nickel, iron, mercury, antimony and a host of others.

That is only a general picture of how ores are born as magma penetrates the rocks of the Earth's crust. The actual processes are more diverse and numerous. They take different turns which depend on the composition of magma, the set-up of adjoining rocks, the rate at which the fiery sea cools, the number, direction and size of cracks, and so on.
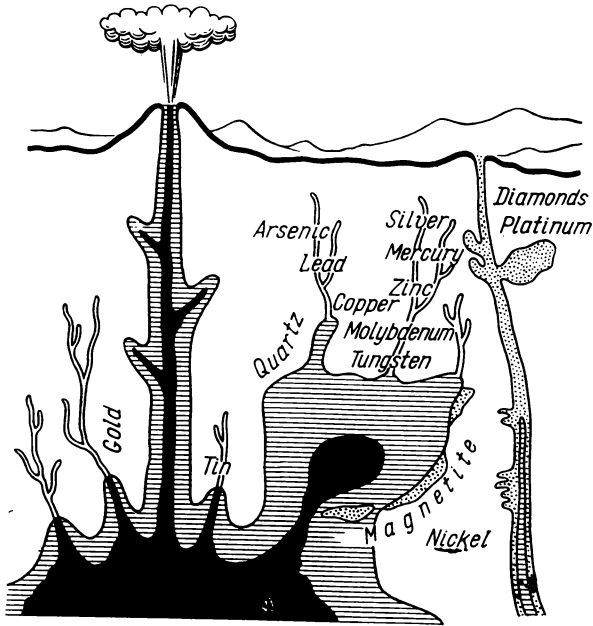
Magma is the source of all metals

Finally, magma has solidified. Millions of years may pass before man runs into the treasures hidden underground. Or the blind forces may break in ahead of man to scatter or amass them.

The Earth's crust has never been immobile. Many of the rock samples mountaineers collected at the tops of the highest mountains have turned out to be sedimentary rocks, i.e., those formed at the bottom of seas. The stony waves of the Carpathians, the proud rocks of the Caucasus, and the havoc of the Kirghizian and Turkmenian mountains were the sea bottom a mere 100 million years ago.

The movements of the Earth's crust can hide ore veins so deep that man cannot yet reach there. We can only guess what a huge wealth of minerals wait for man to come and take them at a depth of three, five or seven kilometres.

With many ore deposits the opposite has happened—they have been pushed to the surface to be worked on by other forces. The planet's surface is exposed to all the elements. It is blown over by winds, burned by the Sun, and wetted by rains. It cools at night and freezes in winter. The rivers dissolve various substances and carry them into the sea. Changes in

the climate work on it, as do the seas, now advancing and now re-treating.

All of these elements also work on the ore deposits which are raised to the Earth's surface. They may be reduced to dust and carried as such by the wind to other places, thousands of kilometres away. They may be dissolved by an advancing sea. A violent river may break up the enclosing rock to leave behind placers of gold, platinum and diamonds, i.e., those substances which prove more durable.

The natural forces acting on the Earth's surface, however, not only destroy, but also build up new deposits of metals. We find them both in volcanic and in sedimentary rocks. The oxides of iron settling on the bottoms of lakes and swamps make up deposits of iron ore. Chalk and lime, which are the salts of the metal calcium, have been formed from sea sediments. There are whole mountains of these minerals in the Soviet Union. Ural bauxites, the ore of aluminium, have been left by Devonian seas.

And today man is using only a tiny fraction of the planet's wealth of metals. The mines and quarries where he gets metallic ores are confined to land. But land accounts for less than one-third of the Earth's surface; more than two-thirds are covered by the blue waters of the seas and oceans. In effect, man has not yet begun to utilize the treasures of the sea floor.

Not that he has explored all of the planet's surface. Geologists have never been to many mountain valleys in Asia, South America and Africa. Their pick has never struck at the rocks of many mountains. Then there are Antarctida with a fantastic wealth of minerals in the few oases, and Greenland covered by an armour of ice.

Nor have geologists peeped deep into the Earth's inside even at the places we think explored. The few drill-holes reaching three to five kilometres into the planet's body and the vague language of geophysical prospecting can still tell very little to man.

But it is both good and bad. It is good because there is much to be discovered yet. It is good because we Earthlings are better off than we think today.

SOVIET METAL

At one time the iron of the "Old Sable" brand was considered the best in the world. That was a grade of iron made in the Urals, Russia. It was this grade Dutch craftsmen had in mind when they said, "There cannot be anything better."

Russia sold quite a lot of iron on the world market. In 1716 Britain bought the first consignment of about 35 tons of Russian iron. In 1732, the

figure exceeded 3,200 tons. That was the metal that went into the foundation of the industrial revolution in Britain in the 18th century.

Russian metallurgists at that time were leading the field of metal-making. Their blast furnaces were the world's best both in design and capacity. They had introduced the double-tuyere blast and had devised a process for making iron from magnetite. This was why Russia dominated the world market in iron. In the 1730's Russia produced more than a third of the world output of iron.

However, the political backwardness of Russia and the lingering serf-dom—and serfs were the main source of labour for the Ural works—prevented the country from holding its leading position. In 1885, Russia made less than three per cent of world iron output. When the 1914 war broke out, Russia was lagging far behind the great powers in production of metal. While in 1913 the per capita production of iron was 327 kilograms in the United States, 228 kilograms in Britain, and 217 kilograms in France, in Russia the figure was 30 kilograms. In 1913 tsarist Russia made 4.2 million tons of iron and 4.2 million tons of steel.

"As to iron, one of the main products of modern industry, one of the pillars of, we may say, civilization, the backwardness and wilderness of Russia are especially great," Lenin wrote at that time.

Although rich in ores of most metals, the country was mining only copper, lead and zinc, and then in quantities which were not enough even for its backward and underdeveloped industry. Russia produced very little, if any, of aluminium, nickel, tungsten, magnesium and chromium. Instead, they were imported.

The first world war and the armed intervention left lying in ruins what metal-making industry the country had. The blast furnaces went cold. The steel works closed down. In 1920 the country made as little as 0.16 million tons of iron and 0.2 million tons of steel.

With the advent of the Soviet system, the people set to work re-building the metal-making industry. The youth went to build metal works as they had gone to attack fortresses during the Civil War. Reports from the construction sites of the Magnitogorsk and Kuznetsk iron-and-steel works were read all over the country as if they were news from the front. Under the first five-year plans major metal-making works went into operation, among them the Krivoi Rog, the Azov Steel and the Zaporozhye Steel plants. In 1940, the Soviet Union made 18.3 million tons of steel and 15 million tons of iron.

Then the 1941-45 war came. That was a trial not only for the stamina and courage of people, but also for the strength of metal. The steel of guns and the lead of bullets, the lightweight alloys of planes and the heavy armour of tanks grappled with one another on the battlefields. The much-praised Solinger steel succumbed to the metal from the Urals. Quite a num-

ber of Nazi tanks crippled by armour-piercing shells, blown-up guns, and abandoned mortars went to open-hearth furnaces to be re-melted into the peaceful metal of post-war rehabilitation.

The post-war years saw a fresh expansion in the production of metal. In 1955 the country produced 45.3 million tons of steel and 33.3 million tons of iron. In 1964, the figures rose to 85 million tons for steel and 62.4 million tons for iron. The Soviet Union is now firmly leading Europe and ranks second in the world in the manufacture of these basic metals.

The manufacture of non-ferrous metals has also skyrocketed. While in pre-revolutionary Russia metallurgists dealt with only sixteen elements and produced them in limited quantities, today the Soviet Union is turning out over sixty metals on a commercial scale. Of course, this figure does not include the metal produced by pilot plants at research establishments.

The Soviet Union has become a major producer of aluminium and magnesium, the metals of aircraft. Now that an ever-increasing number of nuclear power plants are being built, there is a steady increase in the output of uranium, their fuel. There is also a steady expansion in the manufacture of titanium, beryllium and germanium, the metals of the future, the metals of technological progress.

The target for the manufacture of steel in 1980 is a breath-taking figure—250 million tons!

This is the metal work for 10,000 hydro-power stations the size of the Rybinsk Hydro on the river Volga.

This is twenty million heavy-duty Diesel tractors.

This is 112 big turboalternators of 200 megawatts each.

This is the rails for a line two million kilometres long, which could girdle the globe fifty times.

No one, of course, is going to turn all of this metal only into rails or turboalternators. It will be made into turboalternators, tractors, rails, paper clips, cars, frames for houses, vacuum-cleaners for our homes, and a multitude of other useful things. There will be enough metal left to reach the Moon, for by that time many more spacecraft will have followed the first manned probe. They, too, will have taken up some of this metal.

Not that iron spacecraft will be built. Yet, even if they were built entirely of super-lightweight alloys of beryllium, titanium, magnesium and aluminium, they would not be able to shoot off without iron and steel. For steel goes into the machine-tools to work parts for spaceships, and into the plating of the furnaces to melt those lightweight alloys. So iron and steel are the basis of everything.

That is a lot of metal, and its production is growing at an unprecedented rate. Yet, we are short of it. We are still lagging behind some countries in per capita production of metal.

In the past, however, the gap was wider. In 1913, tsarist Russia manu-factured as little as 30 kilograms of steel per head of population, as against 327 in the United States. Since then, by 1960, the United States had doubled per capita output, and the Soviet Union had increased it ten-fold. While in the past per capita output in Russia was one-eleventh of what it was in the United States, today it is more than two-thirds of the United States figure. And the gap will be closing at an ever-increasing rate.

THE MINERAL WEALTH OF THE COUNTRY

The Soviet Union is fabulously rich in the various metals. It ranks first in the world in the explored reserves of iron ores. High-quality ores have been found in many localities. The biggest among them are the Kri-voi Rog and Kerch districts, which account for about a third of the coun-try's total. One-fifth of the total is claimed by the Urals and as much by Kazakhstan. The Kursk magnetic anomaly area also has huge deposits of iron ore, although we do not know final figures yet (its development has begun only recently). Iron ore has been found in the Kola Peninsula, East-ern Siberia, the Lake Baikal area, and the Soviet Far East.

The Soviet Union ranks first in the world in the explored reserves of copper ores. The main suppliers of this metal of electrical engineering are the Urals and Kazakhstan. Also, there are deposits of copper ore in the Caucasus, the Altai mountains, Uzbekistan and Eastern Siberia.

The Soviet Union holds first place in the world in reserves of lead ores. Lead is produced in Kazakhstan, the Central Asian republics, the Soviet Far East, the Urals, the Northern Caucasus, and elsewhere. Zinc is an insepa-rable companion of lead. It, too, has been found in large quantities.

The Soviet Union leads the world in the known reserves of manganese. The biggest deposits have been located around Chiatura in Georgia and near the town of Nicopole in the Ukraine. Manganese ore is also mined in the Urals, Western Siberia, Kazakhstan and other regions.

The Soviet Union tops the list of the countries that have the biggest known reserves of tungsten. It is mined in central Kazakhstan, the North-ern Caucasus, Central Asia, and elsewhere.

The Soviet Union is among the world's leading suppliers of aluminium ores, bauxites and nephelines. They have been found in the Kola Peninsula, the Urals, Kazakhstan, and elsewhere.

The same is true of the ores of nickel, cobalt, molybdenum, antimony, mercury, and platinum. We have large deposits of tin, titanium, that rival of iron, the rare and scattered metals such as uranium, beryllium, lithium,

niobium, tantalum, zirconium, germanium, indium and others on which further progress in engineering is hinged. The Soviet Union also mines the precious metals gold, silver and the platinoids—iridium, rhodium, and palladium.

In a word, "metallic hunger" does not threaten the country. Still....

WOULD-BE ORES

However large the reserves of magnetite in Mt. Magnitnaya may be, they will be used up with time. Since the works went into operation there, the steel jaws of power shovels have gnawed away half the mountain. The day will come when the blast furnaces will swallow the last bite of it.

This is true of any other place, though. There will be an end to the iron ore of Krivoi Rog, Kerch and even the Kursk area, no matter how big their deposits are. Historians might cite many examples of countries which were threatened with "metallic hunger" after they had used up their ores. Is the Soviet Union in for the same fate in the future, whatever remote?

In 1910, an international geological congress was held in Stockholm. On its agenda was the same question "Would the Earth run short of iron ore some day?" Seventy-two countries had sent the Congress information about their ore reserves. After an analysis, the scientists declared that in sixty years there would be no more iron ore to mine, and every nail would be worth its weight in gold, or even more, because iron is more important.

The same point was raised at the International Geological Congress held in Brussels in 1922. And again, the outlook was gloomy, although every year would push back the spook of "iron hunger" with the discovery of ever new ore deposits.

The same fears have been voiced over other metals.

Today we can say with certainty that they are without any ground.

This is because in calculations account is taken only of ores that can be treated for recovery of metals at the present-day state of art. As better methods of extraction are developed, ever leaner ores prove profitable enough to treat.

In the 19th century, copper ore was first roasted to eliminate its sulphur. Then the roasted product was smelted many times to drive off other impurities. That took quite an amount of fuel to burn. Therefore, it was considered profitable to treat only an ore carrying at least six to nine parts of copper in a hundred. The chalcopyrite of the Urals was not considered an ore at all, although huge amounts of it had been discovered.

Then came flotation, a method for enriching copper ores, and a new process for copper smelting. This method uses the heat given up by the

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sulphur on burning. With it, much less fuel is required for smelting. As a result, the same chalcopyrite with a copper content of about two parts in a hundred has now become an ore and not a barren rock, as it was contemptuously looked upon by the copper smelters of the 19th century.

Here is another example. A hundred years ago neither bauxites nor nephelines were taken as ores; what we call the aluminium industry today was non-existent at that time. After the electrolytic process for the manufacture of aluminium had been invented, the former "waste materials" were graded up into ores.

Quite a number of elements important to engineering have been found in dumps, or spoil heaps. When this happens, the "waste" of yesterday becomes a valuable ore.

One way or another, what is a "waste" or a "barren rock" today may prove a valuable ore tomorrow.

You have certainly read Herbert Wells's famous novel "The War of the Worlds". In it he gives a description of an unusual machine built by the Martians on the Earth: "With two spatulate hands the Handling Machine was digging out and flinging masses of clay into the pear-shaped receptacle above, while with another arm it periodically opened a door and removed rusty and blackened clinkers from the middle part of the machine. Another steely tentacle directed the powder from the basin along a ribbed channel towards some receiver that was hidden from me by the mound of bluish dust. From this unseen receiver a little thread of green smoke rose vertically into the quiet air. As I looked, the Handling Machine, with a faint and musical clinking, extended, telescopic fashion, a tentacle that had been a moment before a mere blunt projection, until its end was hidden behind the mound of clay. In another second it had lifted a bar of white aluminium into sight, untarnished as yet and shining dazzlingly, and deposited it in a growing stack of bars that stood at the side of the pit. Between sunset and starlight this dexterous machine must have made more than a hundred such bars out of the crude clay..."

Well, this machine is not an idle dream. Common clay carries a good proportion of aluminium. In fact, there is less copper in chalcopyrite than aluminium in clay. What we need to extract this aluminium is a good process which would make clay an attractive ore. Then Wells's machine will become a hard reality. "Between sunset and starlight" it will be able to turn out at least a hundred bars of aluminium, or even more, directly from clay.

Do you know basalt? Yes, the very basalt, a hard, heavy and dark-coloured rock which sometimes pours out of volcanos. It is as common as

clay. In the Soviet Union, outcrops of basalt occur in Armenia, Karelia, Kamchatka, the Sayans, and elsewhere. Between the rivers Lena and Yenisei basalt covers an area of over 1.5 million square kilometres.

Today basalt is just coming into use in engineering. It can be cast into slabs to line coal pulverizers instead of cast-iron plating, into tubes for the nozzles of sand-blasters instead of sintered carbides, and into ash chutes for boiler fireboxes. However, in these uses basalt is not an ore. Clay, too, is made into brick.

In the opinion of Shcherbakov, a prominent Soviet scientist, basalt is the most promising among the would-be ores. Small wonder, though! It carries forty parts silicon, fifteen parts aluminium, seven parts calcium, six parts iron, five parts magnesium, and two parts titanium in a hundred. That is a rare set of metals. And again, what we need is a good process which would separate the metals and make basalt a profitable ore.

We could cite a great many other examples of how a rock can become an ore. Almost every rock, either igneous or sedimentary, can be a source of one metal or another. And not only rocks. Sea water also carries large quantities of calcium, potassium, sodium, gold, silver and other metals dissolved in it. Some time in the future their turn will come too.

FROM MINE TO FACTORY

Today it seldom happens that an ore goes straight from a mine to a smeltery. As a rule, it is first dressed.

The reason for this is simple. The non-ferrous ores currently used for recovery of metals carry very little of them. As often as not, for example, a lead ore contains one and a half to two parts of lead in a hundred. To keep the smelting process going, the concentrate charged into the furnace should carry twenty to thirty parts of lead in a hundred. Molybdenum ores carry still less metal—an average of a few parts in a thousand. Existing processes call for a charge containing at least forty to fifty parts in a hundred.

This is where ore-dressing comes in.

I happened to trace ore from a mine to an ore-dressing plant once. This was at a lead mine in Kirghizia.

Lead is among the most commonly used metals of engineering. Many of you have probably seen large wooden reels with cable wound on them. This may be a cable for the transmission of electricity or for telephone service. It is buried in ground or lowered on the bottom of a river. To protect the cores from damage, the cable is clad in a lead sheath, a reliable and flexible armour.

Today there is hardly a single person who does not know what a storage battery is. Most batteries also use lead. Heavy slabs of lead make an excellent "biological shield" around sources of radioactive radiation. Lead vessels are a "must" in chemical laboratories handling very aggressive liquids. Lead-base alloys and compounds have found many uses in almost all divisions of engineering.

Now about my visit to the Bourda lead-zinc open-cast mine.

Straining its engine in first gear, our truck slowly negotiated the endless meanders of the road. It ran at about two thousand metres above sea level, higher than the famous Mt. Ai-Petri in the Crimea. We felt fed up with the writhing road when, ahead of us, we saw a sun-lit valley surrounded by greenish-brown mountains. In its cup was the miners' community. The two- and three-storeyed houses stood, cuddling to the mountain sides. Behind them could be seen the green patches of the kitchen-gardens, stretching up the slopes. The rich green of the plants spoke of the soil's fertility. We drove past the community centre, the school building, the canteen, and the hotel. The poles of the electric line climbed up the terraces. The tap-water in every flat came from springs in the mountains. I bet, the community was as comfortable to live in as many a larger city.

"When were they built, these houses?" I asked an old-timer.

"Less than a decade ago," was the answer. "Development work began in 1952. So our record goes back there."

As soon as we left the townlet, the driver shifted back to first gear; the houses stood at the foot of the mountains, and the ore was mined on their tops.

Finally we made the last turn and found ourselves on a huge, unbelievably flat patch of ground covered all over with tyre marks. How in the world could this "pan" appear among the chaos of mountains shooting up into the sky, where the very idea of a level plane seemed absurd? We looked around, and it dawned upon us that we were standing on a mountain with its top snapped off by some huge jaws. That was the open-cast mine where they were mining the famous lead-zinc ore.

Way back, the furious cataclysm of underground forces had split up the brown body of the granite there, and solutions of valuable metals had filled the crack. Now we could see a bluish-violet vein of galena cutting across the mountains. It carried lead and zinc, gold and silver. It would shrink to two or three metres at some places to fan out to thirty or thirty-five metres wide at others. It was because of this vein that a town and an ore-dressing plant had been built in the mountains, trucks arrived, and people were working.

Very few people could be seen on the site, though. The air was filled with the busy rattle of self-propelled drilling rigs making blast-holes ten to twenty metres deep in the granite rock. With slow and important bows,

the Ural-made power shovels were scooping up the ore with their buckets each holding four cubic metres. It was their jaws that had snapped off the mountain top. Rumbling with their engines, the ten-ton dump-trucks were hurrying to the power shovels. Only two persons were not at the controls of some machine or other, a surveyor and a girl, his assistant. "The only two manual workers," they joked.

Our guide was Victor Rudakov, the senior geologist of the mine. Since this was happening before our eyes, only details remained to be filled in.

Now the drilling rigs stopped their rattle. Unhurriedly, they stepped down on their caterpillars from the rock bench in which they had drilled blast-holes. While they were moving out to safety, shot-firers loaded charges into the blast-holes.

Then a warning came from the siren. The miners took shelter, and only the shot-firers were to be seen on the site. They ignited the fuses and hid in the steel buckets of the power shovels. All of a sudden, the rock swayed and flew to pieces; the shock wave of the blast struck at our ear-drums. A powerful echo hopped over the hills and dales.

The people dashed to their machines. The steel booms of the power shovels came to life again, and the dump-trucks resumed their rumbling.

We stepped out of their way to the edge of the site. The ground under our feet was loose, as if it were a freshly ploughed field. That was an unexpected experience among stones and rocks. That was how the blown-up rock "looked". Soon it would be loaded into dump-trucks.

The trucks carrying barren rock and ore took different roads. The spoil was dumped from the precipice straight into the gorge some five hundred metres below. The ore was carefully unloaded into the hopper of a huge jaw crusher.

The crusher department stood close to the side of a steep rock. A narrow spiral staircase took us down, into the machine room. The operator led the way to the narrow ledge of the rock where the sound of the ore crushed by the steel jaws was not so deafening.

"The crusher is the first step in ore dressing," we learned from him. "Lumps of ore, some weighing more than a ton, are reduced here to pieces not more than thirty kilograms in weight. A conveyor carries the pieces to the hopper of a cableway. Its terminal is right here, under our feet. After one kilometre and a half's journey, the ore gets to the ore-dressing plant. Look over there."

There, in the valley, stood the ore-dressing plant, looking like a miniature toy or a pyramid of match boxes. As if proud of their "fare", the full buckets were gravely sliding down the track cable to the plant. Giddily rocking, the "empties" were climbing up the other cable. Farther away,

the white match boxes of houses lined up on either side of the emerald-green valley. We had passed them in the morning.

We picked a few yellow alpine poppies as a keepsake and went to the ore-dressing plant.

Polymetallic ores never carry more than four parts of lead in a hundred. Such ore cannot be charged into a furnace for smelting. It must be dressed, or separated from the waste material. This is done in an ore-dressing plant.

In an ore-dressing plant, the ore is first comminuted, or reduced in size, in grinders and mills. The ore thus reduced goes to the flotation department.

To get an idea about flotation, take a grape and drop it into a glass of soda water. The grape will sink to the bottom, because it is heavier than water. Now a bubble of gas, bright as a droplet of mercury, forms on it. Soon a second and then a third bubble join it. Before long, the grape is covered by gas bubbles as if with tiny beads of silver. The grape sways and floats to the surface, lifted by the bubbles. Such is the principle of flotation.

In the flotation department, a mixture of ground ore and water, called the pulp, is charged into aerating cells. In the cells, the pulp is stirred, air is blown through it, and a good deal of froth is formed on the surface of the pulp. The froth is a multitude of air bubbles ranging in size from a pin head to a watermelon. They show a dull metallic lustre. This is because they carry numerous particles of ore attached to them. The particles of the waste material cannot do that; they sink to the bottom.

Of course, the actual process is not that simple. Quite a number of reagents are added to the water in which flotation is carried out. Some, called frothers, promote the formation of air bubbles. Others, called collectors, make it easier for the ore particles to attach themselves to the bubbles. Still others, known as depressors, do quite the opposite to other ore minerals. So, very subtle physical and chemical processes take place in the seemingly simple cells.

Nikolai Maslenitsky, the process engineer of the plant, who was showing us round the place, took what looked like a big ladle and spooned out some lead-laden froth. He placed the ladle under a jet of clear water, made a few swinging movements, as gold-diggers do when they pan off their gold, and we saw a handful of metallic powder gleaming on the bottom of the ladle. That was lead-ore concentrate. Now it was to be separated from water.

This is done in huge tanks, called thickeners. The concentrate is allowed to settle, and the clear liquid is removed by overflow.

We were surprised to see very few people around. As we walked from one huge department to another, and from floor to floor, we could only see a person or two in each of them.

"Why should they be here?" the guide parred our question. "Everything is done automatically or semi-automatically. We are improving the process all the time. When the plant was just started about six years ago, we had three hundred and fifty workers on the payroll. Today, there are only one hundred working at the plant, from manager down to cleaner. Still fewer will be left with time."

Late at night we set out on our way back to the Chu Valley, and the friendly twinkling of the electric lights on the mountain tops of Bourda followed us for a long time.

UPGRADING THE ORE

Flotation was first used at the turn of the century. As the story goes, it was discovered by the wife of a miner who worked in a copper mine. As she washed his shirt, she noticed that the particles of copper ore would stick to the soap froth, and the earth would be left in her tub.

History has not kept the name of that woman for us. But we have a whole list of flotation inventors who took out patents in different countries at different times.

Today flotation is widely used to dress a large variety of ores. Practical methods differ in the reagents added and in the number of steps carried out. Sometimes, when an ore carries several "values" all mixed together, what is known as selective or differential flotation may be used. But the underlying principle is as we have just learned.

Flotation is not the only method of ore dressing. Nor does the very idea of ore dressing belong to the 20th century. In his book "About Metals", the medieval German scholar Agricola tells us that before they charged an ore into a furnace, the workers usually separated valuable pieces of ore from worthless pieces. That was hand sorting, one of the methods of ore dressing still used sometimes. But again, this was not the beginning of the idea, either.

The Greek geographer and historian Strabo, who lived between 64 B. C. and 19 A. D., wrote "Geography", a work of seventeen volumes. In it he gives a detailed description of the Earth as it was known to the ancients. In the pages about the Caucasus he writes:

"It is told that in their country streams carry down gold and that they... collect it with drilled troughs and wooly hides. This is where, it is said, the tale of the golden fleece comes from."

Actually, this is one of the methods of ore-dressing, known today as tabling. Invented so long ago, it later came into wide use among gold-diggers all over the globe. It is still used today to dress the ores of iron, tin, tungsten and other metals much heavier than the waste rock.

It is only too natural that ore-dressing should use magnetic separation. As we know, ores sharply differ from one another and from the waste rock in magnetic properties.

Today, magnetic separation is gaining ever more ground. It can be dry and wet. In the dry process, particles of an ore over six millimetres across are separated from particles of rock of about the same size by means of magnets in air. In the wet process, the particles are smaller than six millimetres across, and the separation is done in water. The machines used for the purpose are called magnetic separators.

One of them, used for dry separation, is simply a strong electromagnet fitted above the belt conveyor carrying a nonmagnetic ore into a mill for grinding. As the ore, or feed as it is called, passes under the magnet, it picks out "tramp" iron, such as nails, bolts, iron scrap, which might cause damage to the mill.

In wet separation, electromagnets are mounted over the return run of a belt conveyor inside a tank. As the feed passes under the belt, the non-magnetic material settles down, and the magnetic particles are attracted to the belt. The belt carries them out into another compartment to shed them off as soon as they are outside the pull of the magnets.

In electrostatic separation, which is similar to magnetic, all the particles of the ground ore are charged electrostatically and carried over a metal drum. The conducting particles give up their charge to the drum at once and drop into the first bin. The semi-conducting particles are a bit slower in parting with their charge, and drop into the next bin. The non-conducting particles are the last to discharge and get into the third bin.

There are many other methods of ore dressing. Some use the fact that particles of different materials adhere differently to certain agents. Some depend for their effect on the friction between ore particles and the material of an inclined surface. Others separate particles by size. Still others classify them by shape. Combinations of these methods are also possible, especially where an ore carries a number of "values" which should be separated one from another.

MINES OR DRILL-HOLES!

One day I went to a factory producing antimony metal. In one of the shops I saw metal tanks which looked like towers. In them a liquid was gurgling. Those were digesters in which leaching was done, a most impor-

tant step in the metallurgy of antimony. By leaching, antimony compounds are withdrawn from the ore into solution. The solution is then sent to electrolytic cells where antimony is won in metallic form.

Before that we had been to an antimony mine, walked its dark underground galleries with rails for electric locomotives, seen perforators and pick hammers at work in the cutting faces, and gone by a hoist to the other floors of that underground town. Its streets ran several kilometres into the mountains in pursuit of a thin vein of ore. It was both hard and, sometimes, dangerous to win those glittering, light-grey crystals.

It was there that I recalled an old dream about metals being won like oil or water, using drill-holes instead of costly mines.

"An idle dream," you might say.

No, it is not. There is a good deal of scientific evidence that it can be realized, and in the not too distant future for that matter.

"But oil and water are liquids," you might return, "and ores are solids. How can they possibly be pumped up narrow drill-holes?"

Exactly as the antimony solution is pumped from digesters into electrolytic cells through much narrower pipes. Then all that has to be done before leaching could be dispensed with, and the leaching operation could be carried out underground.

The whole scheme would require two drill-holes sunk as far as a deposit of antimony ore, and a third one run horizontally to connect the first two across the ore body. Some remote-operated machines could be installed in the horizontal hole to crush and grind the ore for better leaching. Then a leaching agent would be pumped down through one of the vertical holes, and the antimony solution would be pumped out of the other hole to go direct for electrolysis.

Antimony is not the only metal to which this method can be applied. Hydrometallurgy, of which leaching is one of the basic processes, has been successfully employed to extract copper, cadmium, silver, manganese, gallium, molybdenum, cobalt and some others. As a matter of record, copper has since long been leached out of its ores underground in the Urals. There is no reason why this method cannot be extended to include other metals.

In Italy, a similar method is used to produce sulphur from underground deposits. It takes advantage of the fact that sulphur melts at about 116°C. Sulphur is melted underground by pumping steam under high pressure into the deposit. The molten sulphur is then pumped to the surface.

In many places common salt is produced that way. First, a well is drilled, then hot water is pumped in, and finally the brine is pumped out.

This is a very promising method for the future development of mining. The more so that we cannot increase the depth of mines endlessly because

of the prohibitive rise in temperature. In the East Rand mine in Transvaal and in the Champion Reef mine in India, which are about 3,500 metres deep, deeper than any other mine in the world today, they have to use intensive cooling and ventilation to make work there more or less endurable. But there is no depth limit for drill-holes (since only machines work in them), and they have doubled the maximum depth for mines.

With time, man will have to reach ever deeper into the Earth's insides for the metals he needs. For this, he will undoubtedly rely on drill-holes, not mines. And what we call hydrometallurgy today will surely be their companion.

METALS IN FLOWERS

Standing quite apart is the problem of the so-called trace elements. They do not form large ore bodies, have no minerals of their own, and are found only in minute quantities in other rocks. Their atoms are scattered about the crystal lattices of other substances. Among them are the metals scandium, gallium, rubidium, thallium, niobium, indium, cesium, tantalum, germanium, selenium, tellurium, hafnium, and rhenium.

Most of them, though, can only be met in the Periodic Table. Some have come to be used very recently. Indium and niobium were first used between 1930 and 1940, gallium and germanium between 1940 and 1950. Others, such as yttrium and rubidium, have not yet been used at all in any form, neither as pure metals, alloys, nor as chemical compounds. But this is not to say that they are useless to man. With some, poor knowledge of their properties have prevented their use. This was so with titanium which had for a long time been thought too brittle and weak, and with germanium which is the basis of semiconductor engineering today. It may well happen that the least known of the metals will prove most important to the engineer to-morrow.

The current practice is to win trace elements from the ores of other metals in which they are usually present in small quantities. Man, however, is looking for other, more abundant sources of these elements. One such prospective source is sea water.

Sea water carries almost all metals, including the rare ones, dissolved in it. There is no denying, their concentration is very low. Sodium accounts for over one part (by weight) in a hundred, magnesium, which is the second abundant metal dissolved in sea water, for as little as fourteen parts in ten thousand, and there is only four parts each of calcium and potassium in ten thousand. The share of the rare elements is still smaller. Every cubic metre of sea water, it has been learned, carries two grams of rubidium, one and

a half grams of lithium, four-hundredths of a gram of selenium, and one-hundredth of a gram of germanium.

To show how great the reserves of metals dissolved in sea water are, figures are usually quoted for all the seas and oceans on the Earth. Those are breath-taking figures. To believe them, there are 5,500 million tons of scandium and still greater quantities of germanium, cesium and selenium dissolved in sea water. Unfortunately, those figures hide a big snag.

The trouble is that to get all of this scandium, we should have to filter all the sea water of the planet. That would be a project too fantastic to realize even in the centuries to come. Still, it would be unreasonable to give up the idea of using the treasures that sea water holds. One way would be to concentrate these metals in a few places.

But how can this be done? How can one "lure" all dissolved gold into, say, the Azov Sea or all germanium into the Gulf of Finland?

Something of this kind, although on a modest scale, can be done with the aid of sea animals and plants. Metals are part of their structure and play a very important role in it.

Thus, iron is the most important constituent of haemoglobin, the oxygen-carrying pigment of the blood, which gives it its red colour. When about one hundred and fifty years ago the chemical composition of the blood had been determined, a young man deep in love with a girl thought of presenting her with a ring made not of gold, but of the iron of his blood. We do not know the end of this touching story. But the blood hardly has enough iron for a wedding ring. There are only a few grams of it there.

The human body contains zinc, copper and cobalt. It is believed that nickel gives the human hair a light colour, titanium makes it golden, while molybdenum turns it red. We find also the rare metals uranium and radium in the human body.

Metals are found in animals, insects, land plants, sea weeds, and single-cell organisms. What is especially interesting is that each species concentrates some particular element. The sea-squirts in the Gulf of Kola carry about five parts vanadium in a thousand, while its content in sea water is as low as five parts in a hundred million. A species of marsh horsetail is capable of accumulating gold. When burned, its ash carried over 600 grams of gold per ton, although the soil assayed only 0.1 gram per ton. In sea plants there is a hundred times as much radium as in sea water.

The same is true of land plants. One gram of the dry substance of puffball carries a quarter of a gram of zinc. The ash of some plants growing on zinc-rich soil contains up to 294 grams of this metal per kilogram. This is a veritable zinc concentrate which can be smelted directly, without any upgrading.

The ash of some grasses and leaves contains up to one part of germanium in a hundred thousand, while its average content in soil does not exceed seven parts in a thousand million.

The ash of a species of laurel has been found to contain as much as fifteen parts of manganese in a hundred.

Geochemists know quite a number of large mineral deposits whose origin can be traced back to this amazing ability of living things to concentrate certain elements. As Academician Vernadsky, the founder of bio-geochemistry, a new and thrilling science, writes, "Iron, manganese, and aluminium ores are in a great or probably in the main part related to organic life. Organic life has given birth to deposits of phosphorus, saltpetre and native sulphur. There is reason to believe that organic life has contributed to some of the ore deposits of copper, vanadium, silver and lead." So, organic life is the most efficient accumulator—in the geological sense of the word—of certain elements.

Then why not to utilize this ability for winning metals from the seas and oceans?

Man has for centuries been improving the apple-tree. From a forest wilding with sour, hardly edible fruit the size of a nut, he has evolved dozens of varieties bearing apples widely differing in quality: sweet, soft, non-perishable, sour, hard, and so on. Man has changed wheat to a point where scientists cannot tell which plant it has sprung from. The dachshund with its short crooked legs and long body and the bulldog with its powerful head are a far cry from the wolf, their ancestor. This is also due to man's effort.

However, none of the geneticists has ever thought of evolving a variety of cabbage which would collect germanium or lithium, a breed of pigs whose bones would concentrate tellurium or actinium. Yet, this task could be accomplished.

In all probability, the most suitable "stock material" for this purpose would be the simplest single-celled organisms, such as bacteria, algae and fungi. They multiply quickly and can be easily changed by the various external factors that geneticists have at their disposal today. The mould from which penicillin is obtained originally had a productivity factor of 40 to 80. After conditioning with X-rays and ultra-violet light and close screening, the productivity factor of the mould has been raised to over one thousand. It is not unlikely that by the same technique we could improve hundreds of times the ability of the simplest organisms to concentrate the rare elements. In the Soviet Union, the United States, Canada and Britain research is under way on the use of bacteria for the treatment of ores, such as copper sulphides, by oxidation and conversion into a soluble form.

In 1934 the Czechoslovak chemists Babichka and Neman found that the ash of some of the plants on the outskirts of the town of Oslani carried up to ten grams of gold per ton. The soil in that locality assayed not more than two-hundredths of a gram of gold per ton.

"Why, the animals feeding on the plants may well concentrate the metal still more," the two chemists thought.

Their guess proved correct. The ash of cockchafers was found to contain as much as twenty-five grams of gold per ton.

This finding suggests a practical approach to the problem of artificial concentration of the trace elements. This could be done in two stages; the first by means of plants or bacteria, and the second by means of insects or fish.

There is another interesting discovery worth mentioning. Everything began with the experiments of the German chemist Vogel who lived in the early 19th century. He sowed lettuce in a bed of crushed glass which contained no sulphur, either in pure or in compound form. He watered the lettuce with distilled water, and covered the plants with a glass bell to shut out the sulphur contained in the atmosphere. Then he burned the lettuce and found that the ash carried twice as much sulphur as its seeds. Where had it come from?

In 1876-83 these experiments were repeated by a biologist in Berlin. He had extended the scope of the experiment to cover other elements, such as potassium, phosphorus, calcium, sodium and magnesium, in addition to sulphur. As he found, the yield of these elements did not tally with their intake.

More recently, Vogel's experiments were repeated by the French scientist Beranger. With all the fine experimental techniques of the mid-20th century and every possible precaution, he made one experiment after another only to find that the intake and yield of some of the elements did not tally.

The scientist offered a bold explanation. To believe him, the green leaves of plants convert some elements into others. What is done on a negligible scale and with great difficulty in huge particle accelerators, plants appear to perform easily and on a far larger scale.

It is extremely difficult to accept Beranger's hypothesis. Rather, his experiments have proved the remarkable ability of plants to catch the elements they may need, even though these elements may be present in minute quantities. Here we have another proof that plants can and must be used for the concentration of trace elements.

Let your fancy take you into a year which is in a very remote future. Your electromobile which replaced the crude petrol-burning thing long ago is smoothly riding a plastic-paved road. On your left you can see fields covered with blue flowers which look like the poppies of the 20th century.

Do not try to find the plant in botanical atlases. It has been evolved only recently. What man has sought to obtain in it is not beauty, strong fibres,

or tasty and filling fruit. The plant serves a different purpose. It is a concentrator of rhenium, a metal which has come to the fore in semiconductor engineering in recent years.

On your right are vineyards. The vine, too, is unusual. Its heavy, orange-coloured grapes hanging in large clusters from the branches carry rubidium, another rare metal, in quantities ten thousand times greater than the local soil. This variety, which is neither eaten as fruit nor used in making wine, has also been evolved by geneticists. Where this strange vine collects hundreds of kilograms of the rare metal per hectare is its secret. We do not care, though.

Instead of going to a food-processing factory, all of these plants are sent to metal-making works. Both the blue poppies and the orange-coloured grapes are ores, ores artificially grown in the field. Living ores.

Or perhaps everything will be different. The road will take you to a huge factory on the shore of a sea. The chief engineer will tell you what they do and how. That will be a biochemical-metallurgical plant producing some very important and very scattered metal. Big pumps draw in water from the sea into tall towers. In the towers microscopic mould is grown, capable of extracting all the values from the sea water. In the final stage, this mould, like an ore, is smelted into the metal in electric furnaces.

Or you may see underwater plantations of algae with which the whole process of extracting the rare metals is reduced to burning the weeds and collecting the metals from the ash—much as iodine is obtained today.

Those are unimportant details, however. The main thing is that man will undoubtedly use biological concentrators of rare metals. Their day is not far off.

ARTIFICIAL ORE

It may so happen, however, that nuclear physicists, and not biologists or geneticists, will come to help metallurgists with the rare metals.

In the Middle Ages, two things lured alchemists, the philosophers' stone which was supposed to be capable of changing base metals into the noble gold, and the elixir of life which could prolong life indefinitely. Side by side with them, medieval mechanics were working on the perpetual motion machine.

No one knows how much effort, how many sleepless nights, passions, hearts and lives were wasted on those sham projects. Today's science holds entirely different views on the three problems.

"The perpetual motion machine is an unattainable thing," physicists say, pointing to the law of conservation of energy. Today it has become the symbol of wasted effort.

"We cannot say with certainty whether or not eternal life is possible,"
biologists and physicians say. "In all probability, man can live two or three
hundred years. There is no known reason why this should not be so. Unfor-
tunately, we do not yet know how to tackle the problem. It may well take
several generations of scientists to find a way of controlling ageing or to
discover a law of nature setting a limit to the life span of human beings."

"No one doubts today that some elements can be changed into others,"
physicists are happy to report. "In fact, we have already learned how to
do this. There is a commercial process for making plutonium, a metal non-
existent in nature, but important to power generation. We can make a whole
range of radioisotopes with 'lives' of several hours to several weeks, also
non-existent in nature. They can all be bought at special shops. Gold, too,
can now be prepared from base metals, and not only the variety made by
nature. To date, eight species of gold have been prepared, differing in atomic
weight but similar in all chemical properties."

So, present-day physicists can do all that frustrated medieval alche-
mists. True, man-made gold is still more costly than the natural one found
on the banks of the river Lena or Klondike. It is also true that radioisotopes
cost a lot of money yet. But this was so with aluminium, titanium and high-
purity silicon when they were first prepared. Today, aluminium has become
a household thing, titanium is crowding out iron, and silicon cells are now
made by automatic production lines such as the one exhibited for the first
time at the USSR Economic Exhibition in 1959.

Elements are transmuted through nuclear reactions. Physicists have
got a clear picture of most of them. They can say in advance which nuclear
reaction will produce what. So they can transmute elements to a plan rather
than on the off-chance. This led Bardin, a leading Soviet metallurgist, to
draw an encouraging picture of what metallurgy may look like in the future.

"Ours is the nuclear age," he said. "Instead of the temporary and un-
reliable bonds in the atom, man has come to control the more important
and fundamental bonds between the elementary particles in the nucleus.
There is no reason why this basic discovery of our time should not find ap-
plication in metallurgy."

This is how the scientist envisages a nuclear steel works of the future.
Molten steel is tapped from a furnace and poured into the mould of a contin-
uous-casting machine. Two pear-shaped things are fitted on either side of
the stream of molten metal. Those are irradiators, or sources of nuclear
radiations. These radiations pierce the stream of molten metal to break up
the nuclei of the impurities sulphur and phosphorus and also of a cheap
element added to the steel in advance. This element has been so chosen that
irradiation turns it into the metal required to alloy the steel.

In a few seconds, a white-hot strand of metal emerges from the casting
machine. It differs in chemical composition from the molten steel poured

into the mould. The composition will keep changing for a few more days, until all the short-lived elements produced by irradiation disintegrate. Now the metal, of high quality and carrying quite a number of elements made by man and not by nature, is ready to be put to some use.

In Bardin's opinion, a similar process can be used to prepare the rare and trace elements. The chances are irradiation metallurgy, an industry in its own right, will come into being soon to supply man with rare elements made from ordinary ones.

That is an encouraging perspective. And no one today can say who will be the first with their answer, geneticists with "live" rare-metal concentrators, or physicists with nuclear processing. For man may take many roads into the future. Science, engineering and industry will help him to take the easiest and shortest one.

3

THE CHIEF METAL
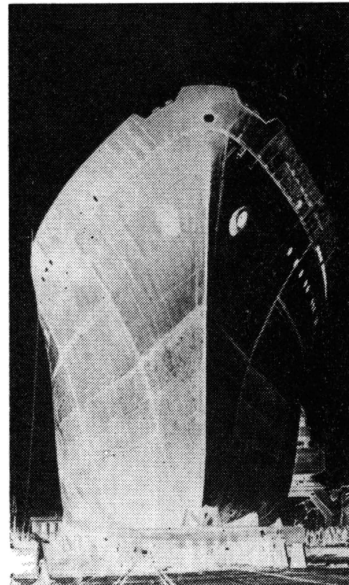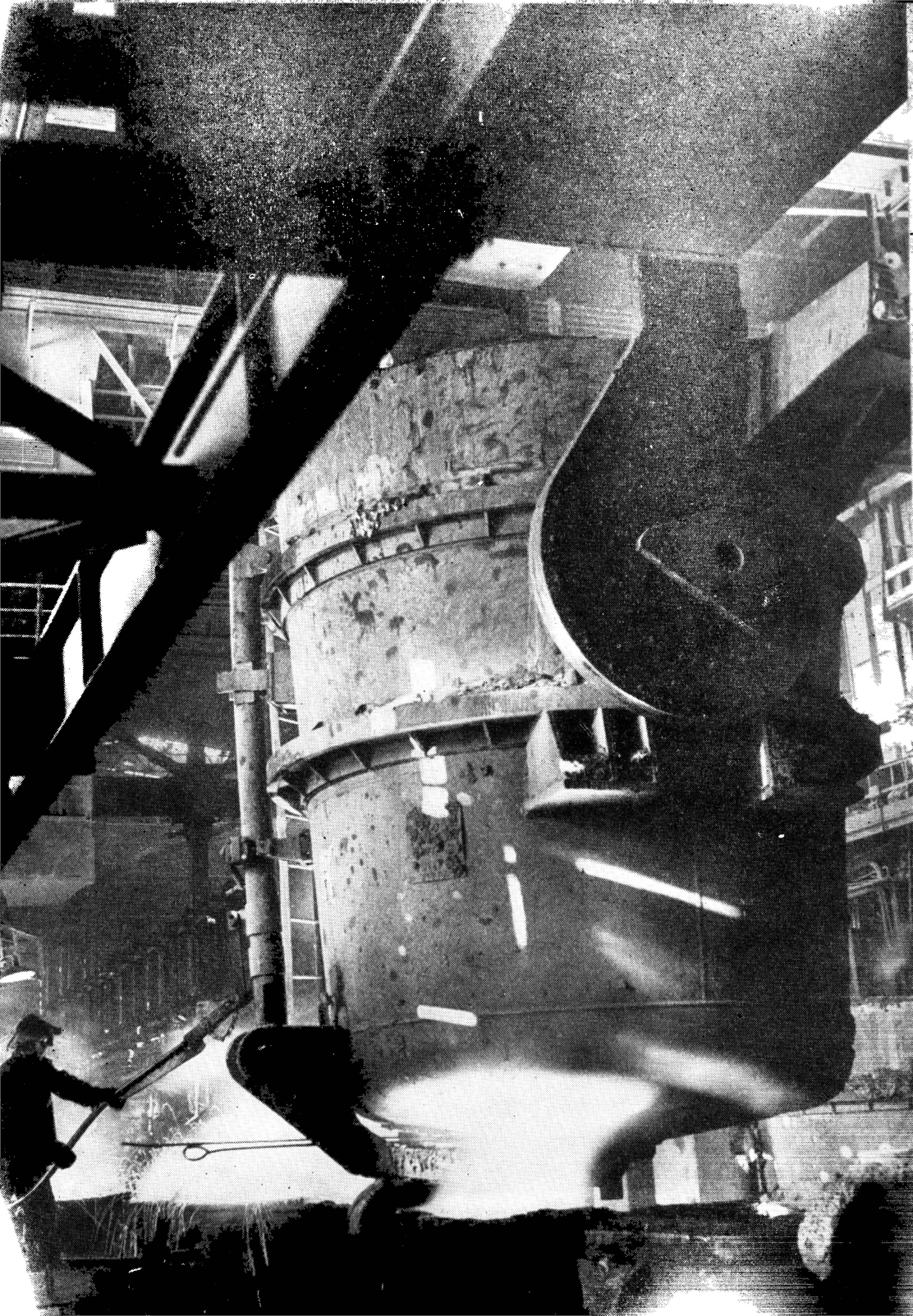
Man first came upon this metal in the Stone Age. Sixty centuries ago the ancient Egyptians made ornaments from it. The ornaments were probably priced higher than those made from gold, for this metal was rarer than gold. Man could find it only in meteorites.

About forty centuries ago, man learned how to win this metal from ore. This may have happened in Egypt or Mesopotamia. In any case, archaeologists have found fragments of tools made from this metal in the Great Pyramid of Cheops. Over 3,000 years ago this metal became known to the Greeks and the ancient peoples of the Caucasus. In China, the metal turned up some five hundred years later. The aborigines of Americas and Australia learned about it as late as a few hundred years ago.

Wherever it came along, the new metal fully ousted stone as the material for tools and weapons. It was made into swords and axes, utensils and ornaments, ploughs and hammers. It also ousted bronze which had given its name to a whole age in man's history. Now the new metal gave its name to a new age.

Historians do not extend this age to include our time. They stop somewhere in the beginning of the Christian era. But this is not to imply that it has fallen out of use since then. During the past millenia, it has found thousands of new uses, improved its properties manyfold, and revealed new po-

tentialities and qualities. Today, it is produced in quantities thousands of times greater than ever before.

Its production has especially expanded during the past century. In 1840, its world output was only 2.3 million tons. In 1897, the figure rose to 3.3 million. In 1960, the production exceeded 225 million.

In the 18th century, its uses were limited to weapons, anchors, anchor chains, nails, buttons, buckles, files, knives, saws and axes. In the 19th and 20th centuries, the number of products made from this metal grew at a neck-breaking rate.

In 1779, England built its first bridge from this metal. Today we can hardly count all the bridges made from this metal across rivers, gorges, canals and straights.

In 1787, the first vessel made from this metal was launched. That was a river boat of about twenty tons displacement. Today, thousands upon thousands of ships, veritable floating towns built of this metal, are plying the seas and oceans of the planet.

In 1788, the first forty miles of water pipes made from the same metal were laid in Paris. Today, a dense network of pipelines covers all the continents, carrying water, oil and gas for distances of many thousand miles.

By far the greatest quantities of this metal have gone, however, to build railways, called by its name in many languages.

On June 14, 1830, the English miner and mechanician George Stephenson emerged victorious from a competition of locomotives. His "Rocket" made about 20 miles an hour. "It flew like the wind," the spectators said. That was the birth of a new type of transport.

As Bardin has aptly noted, all of present-day civilization hinges on the several thousand million tons of this metal extracted from ore and made into machines and structures.

The name of this metal, the chief one in man's history, is iron.

ITS WEIGHT IN GOLD

Very few people, researchers and metallurgists, can say they have ever held a piece of pure iron in their hands.

This may sound strange, but it is true. I bet this has never happened to you. For all that we call iron is in fact either cast iron or steel, alloys of iron and carbon. Pure iron belongs in research laboratories only. Iron costs so much to purify that in pure form it may well be as costly as gold.

Pure iron is a lustrous, silvery-white metal, tough and malleable. It melts at 1539°C and boils at about 3000°C. Pure iron is not strong. So it

cannot be used for bridges, the framework of tall buildings, ship hulls, or machine parts. At best, it might be made into ornaments or some of the utensils such as pails and mugs. Fortunately enough, iron can be made as strong as steel.

Before we learn how this can be done, it is good to learn a few facts about iron itself.

Many a scientist has carried out an experiment, both simple and very hard to explain. In this experiment a piece of iron is put in a porcelain crucible, the crucible is placed in an electric furnace, and the furnace is heated. For some time, the temperature rises and then comes to a stop. Although the meter keeps running, indicating that the iron goes on to pick up more heat, its temperature does not rise. After a few minutes' break the temperature again rises in step with time, until it comes to another stop. And again, while the metal keeps absorbing more heat, it does not rise in temperature. Now, after the stop, another rise in temperature follows, then another stop, and the metal finally melts.

It looks as if, on heating, iron climbs a stairway with broad landings where it stops to take a fresh breath. For pure iron, these "landings" always mark certain definite temperatures, the first at 768°C, the second at 910°, the third at 1400°, and the fourth at 1539°C, where iron melts. Similar "stops" are observed when iron freezes and cools.

It was a long time before scientists could explain the cause of these stops. The first to do this was Dmitry Chernov, a Russian metallurgist, who watched steel ingots cool in his ingot-casting bay without any thermometers or electricity meters. Today, scientists have got a clear picture of what is going on in iron on heating and cooling. This is what they have to say about these "stops", or critical points, as they are scientifically called.

The first critical point at 768°C marks the loss by iron of its magnetic properties on heating. Below that point, it is magnetic; above, it is not. On cooling below 768°C, iron again becomes magnetic. At 910°C, which is the second critical point, the whole of the crystal lattice of iron is changed. Below that point, iron is body-centred cubic, and is called alpha iron. There is one atom at each corner and one atom at the centre of the cube in such a lattice. Above that point, alpha iron changes to gamma iron, a face-centred cubic structure in which there is one atom at each corner of the cube and one atom at the centre of each face. It is this change in structure that absorbs heat while the temperature of the metal does not rise.

Since gamma iron has five atoms more in the lattice than alpha iron, the atoms in it are more closely packed. Therefore, at the second critical point iron undergoes changes in volume and in some other properties.

At 1400°C, which is the third critical point, gamma iron changes back to a body-centred cubic structure, delta iron, and remains such until the metal melts.
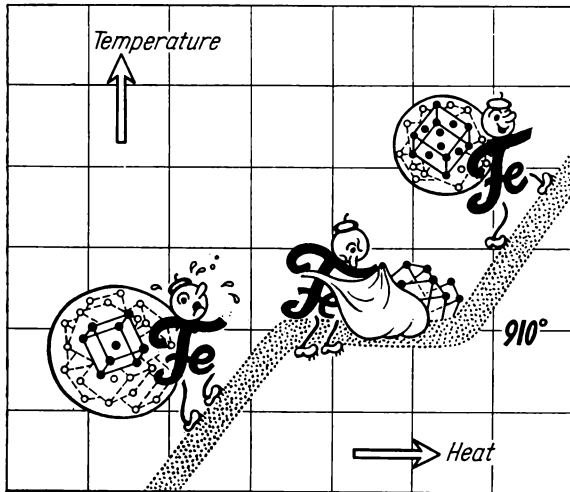
Stopping for a fresh breath

Iron is a good "mixer". Except alkaline and alkaline-earth metals and, in most cases, silver, mercury, gallium, lead and bismuth, it makes alloys with all other metals. However, the most important of all alloys is that of iron and carbon. It makes a whole range of steels.

A CHART THROUGH THE LAND OF IRONS AND STEELS

Strange as it may seem at first glance, metallurgists have been mostly concerned with iron-carbon alloys which carry under seven parts carbon in a hundred. Yet it is this range from a fraction of one to six-odd parts carbon in a hundred that encompasses all the multitude of carbon steels and irons of importance to engineering today.

It has been learned that even the minutest variation in carbon content and in the past history (heating or cooling) of an alloy changes its properties,

or constitution, as metallurgists put it. This knowledge has been built into the so-called constitution diagram. This diagram is to the metallurgy of iron what the Periodic Table is to chemistry. Here it is.

The lower horizontal axis gives the carbon percentage in iron from zero (carbonless iron) on the left to 6.67 per cent on the right. The thing is that iron forms with carbon a compound having the formula Fe_3C, technically classified as cementite and often called combined carbon or iron carbide. It contains exactly 6.67 per cent carbon and is extremely hard and brittle. So, what we have is a system "iron-iron carbide", the reason why the diagram is called the "iron-iron carbide constitution diagram".

The vertical axis gives the temperature of the iron-iron carbide system.

The top line in the diagram is called the liquidus. Above this line, there is only a molten solution of carbon in iron. It is at this line that the molten alloy begins to freeze on cooling.

As the carbon content in the system increases, the liquidus first falls off and then sharply rises. From this we conclude that the freezing point is different for alloys carrying different amounts of carbon. It is lowest for an alloy containing 4.3 per cent carbon. This is a eutectic, or the most easily melted alloy that can be obtained from the same constituents. The iron-carbon eutectic melts at 1130°C.

Just below the liquidus is the solidus. It starts from the same point as the liquidus, for pure metals have a definite melting point, then it sharply drops and turns into a straight line running parallel to the horizontal axis. This change occurs at 1130°C, or the eutectic temperature, and at a carbon content of two parts in a hundred. This content is the limit of solid solubility of carbon in gamma iron.

Between the liquidus and solidus the alloy is partly solid and partly liquid. Among metallurgists, this is known as the mushy stage. On cooling down towards the eutectic point, austenite, or a solid solution of carbon in gamma iron, is rejected as crystals from the "mother liquor". In the hypereutectoid region, crystals of cementite separate from solution. At the solidus, the alloy finally grows solid. Below the solidus there is nothing but a frozen alloy, but changes in it keep taking place.

Find on the diagram the point corresponding to pure (carbonless) iron heated to 910°C. For pure iron, this is the critical point at which alpha iron changes to gamma iron on heating and back on cooling. Note the line starting out of this point and going down to a temperature of 723°C and a carbon content of 0.8 per cent, or the eutectoid point. There, it steeply goes up towards the already known eutectic point —a temperature of 1130°C and a carbon content of two per cent. This line marks off the region where alpha iron changes to gamma iron. Above this line, there is only gamma iron. Another, horizontal, line drawn through the eutectoid point marks off where the transition from alpha to gamma iron and back stops.
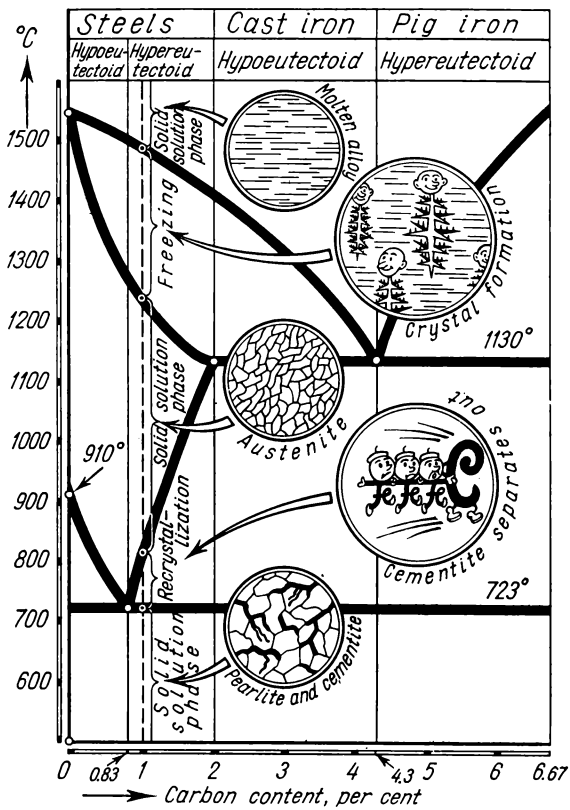
Fortune-telling for metals—from a diagram

The diagram has some more lines, especially in the low-carbon region, each telling of a particular change in the alloy. However, they lie beyond the scope of our book.

To get a better idea of what the constitution diagram can tell us, consider the cooling of an iron alloy containing about one part carbon in a hundred.

Looking at the diagram, you can tell that at about 1470°C austenite, a solid solution of carbon in gamma iron, is thrown out. Austenite is soft and plastic, a feature well known to blacksmiths. They heat the metal to produce austenite before forging.

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At just below 1250°C, the alloy becomes fully frozen. The large crystals of austenite take up all of its volume. At this point all of the carbon is in solid solution in the iron. It breaks into the face-centred crystal lattice, slightly expanding the structure which is too cramped for it.

The austenite remains intact until we reach another line at just above 800°C.

We have assumed that our alloy contains one part carbon in a hundred. We have also noted that all of it is in solid solution. As you will recall, the limit of solid solubility of carbon in gamma iron is two parts in a hundred at the eutectic point. Now that the alloy has cooled to 800°C, the austenite cannot hold as much carbon. So it breaks down, throwing surplus carbon out of its lattice. The carbon leaves, taking along three atoms of iron for each carbon atom to form iron carbide or cementite.

The precipitation of cementite goes on until a temperature of 723°C at which as little as eight parts carbon in a thousand remain in solid solution in the iron. Now the remaining austenite changes to a mechanical mixture of cementite and ferrite, or alpha iron containing very little carbon in solid solution. Since both are rejected at one and the same time, they form alternate plates. This microstructure is called pearlite because, when polished and etched, it has a pearly lustre. This will be the final structure of the alloy at room temperature.

Now suppose that our alloy contains eight parts carbon in a thousand. We heat it to above 723°C so as to bring it into the austenite region, and hold it there for some time to make sure that all of the cementite breaks down and the carbon goes where it belongs in the solid-solution crystals.

Now we slowly cool the alloy. The best way to do this is to turn off current and leave the crucible in the furnace to cool together. In this way we get a pearlitic metal. It has a hardness of 200 on the Brinell scale.

Or we may take the crucible out of the furnace and allow the metal to cool more rapidly in the air. The fresh air adds more strength to it, and the metal has a Brinell hardness of 300.

Still another way of cooling the metal is to dip it in a bath of hot oil. The bath oil, too, proves wholesome, and the hardness of the metal rises to 400 Brinell.

Finally, we may quench the metal in water. As we dip it there, a cloud of steam shoots up, and the water boils. After it quiets down, we take out the metal and measure its hardness. Now it is 600 Brinell. A water bath is as good to metal as it is to athletes.

With the constitution diagram before his eyes, the metallurgist can say at any time to what temperature an alloy of any composition should be heated so as to harden it if it is soft or temper it if it is hard.

There is another conclusion we may draw from the diagram. The more there is carbon in an alloy, the harder it is. This is because the metal carries

more cementite, which is hard and brittle, and less ferrite, which is nearly carbonless iron.

The vertical line through the eutectic point separates the steel region, with zero to 2.0 per cent carbon, from the cast-iron region, with 2.0 to 4.3 per cent carbon. So, the main thing that makes the two "great families" different is the amount of carbon they have.

Before we finally part with the constitution diagram, let us have another look at it.

The region as far down as three parts carbon in a thousand covers low-carbon steels, also known as soft or mild. They can be readily bent, pressed, or drawn while cold. They machine well, producing a long and continuous chip. They are good to weld and gas-cut. But you will not be able to harden them.

Next comes the region up to seven parts carbon in a thousand. The steels in this region are strong, elastic and still machine well. They can be hardened to give them much greater strength.

These steels are classed into structural and machinery, because they go to make machine parts, shafts, axles, wheel rims, bridges, girders, beams, bolts, nuts, nails, springs, and so on. Of course, a particular grade of steel is used in each particular case.

Now we have come to the region up to thirteen parts carbon in a thousand. It covers tool steels. These steels go to make metal-working tools, cutting, shearing, forming, drawing, extruding, and so on. Before use, finished tools are hardened in air, oil or water to make them as hard as necessary. And they are hard indeed.

As we move on through the diagram, we come to cast irons. Very recently they were used only to cast such crude things as bedframes for machines and presses. Today their quality has been improved to a point where they can be made into crankshafts for automobiles. But we shall take up cast irons later on. Past them we run into pig iron, the raw material for steel making and cast irons.

A chemist, with the Periodic Table before him, can tell much about the properties of a metal. So a metallurgist, using the constitution diagram, can tell as much about the properties of steel, although he may have seen it never before.

THE ROADS TO THE BLAST FURNACE

An iron and steel works is an impressive sight. It shook the imagination of the writer Kuprin sixty years ago. He gave it the name of Moloch, an ancient god to whose image children were sacrificed as burnt-offerings.

"That was both a frightening and an exciting picture. The people were

toiling as if they were parts of a huge but precise mechanism. Thousands of them —engineers, masons, mechanics, carpenters, fitters, diggers, joiners and smiths—had come here, driven by the iron law of survival, to give up their strength, health, intellect and energy for another step forward in technical progress."

Today, the works has changed socially beyond recognition. The trades of the people who keep it running have changed as much. And the look of the works is now more impressive than ever before.

The heart of any iron and steel works is its blast furnaces. Running to them are tens and even hundreds of kilometres of railways and motor roads from ore mines, collieries and limestone quarries, and water pipelines large enough to carry whole rivers. Crowding round them are stockyards for coal, coke and ore, ore-sinter plant, coke ovens, hot-blast stoves, steel-making plant, and rolling mills, so big they are works in their own right. Some of them "feed" the hungry blast furnaces, others process what the furnaces make.

Like the threads of a cobweb, the various materials converge at the blast furnace. Like the rays of a star, the sparkling metal, valuable slag and combustible gas radiate from it.

There seems to be only one way to get a clear idea of this motley picture. It is to trace each of the various materials on their way to that knot which is called the blast furnace.

So we shall begin with ore.

The blast furnace is a very squeamish thing. Although it swallows quite a lot, it will not take in just any ore. Every trifle may set off all sorts of troubles in its iron stomach, less pig iron will be tapped from it, and of poorer quality into the bargain, or a chilled hearth or a scaffold may develop.

In the past the mere thought of a chilled hearth or a scaffold would make blast-furnace operators or works owners shudder. No one knew the reason why such things happened. It might well be too much of fines in the ore, or a poor quality of slag, or a cold blast because of the operator's negligence. One way or the other, an incrustation consisting of fused metal, unburned coke and frozen slag would happen along in the furnace, growing all the time until the blast was cut off and the furnace went dead.

Sometimes it was much harder to re-start the furnace with a chilled hearth or a scaffold than to build a new one. Then the faulty furnace had to be pulled down, the scaffold blown up with a charge of dynamite, and a new furnace built. And all this because of the failure to reckon with the furnace's squeamishness.

If a blast furnace is to run smoothly, it should be "fed" with one and the same food. Of course, it may be adjusted to take in any ore, coke and flux and to run at various rates. But once adjusted, the furnace's feed or charge, as it is called, must be kept constant both in quantity and in quality.

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This brings us to the preparation of ore, the main constituent of the charge, before it is dumped into the blast furnace.

It often happens that an iron works has to use ore not only from different mines in the same locality, but from deposits thousands of kilometres away from one another.

In the Soviet Union, the best grade of ore comes from Mt. Magnitnaya in the Urals. It contains over sixty-one parts iron and as little as a few hundredths of one part impurities in a hundred, such as sulphur and phosphorus. The second best is ore from Krivoi Rog in the Ukraine. It assays fifty-nine parts iron and twice as much of impurities as the Ural ore. The magnetite ore from Mt. Vysokaya carries fifty-five parts iron, while Kerch ore from the Crimea has to be dressed to raise its iron content to fifty-one parts in a hundred.

But the iron content is not the only thing that matters. The size of the ore lumps is also critical, because on it depends the passage of the blast through the stock and the amount of ore spent. If the charge carries a large amount of fines, the fine material will be carried off with the gases, and a good proportion of ore will be wasted.

The porosity and shape of the ore lumps have a direct bearing on the rate of the chemical reactions that take place in the blast furnace, and this also tells on the consumption of fuel.

The impurities are every bit as important. They govern what flux should be added to the charge and how much. Their content, especially that of phosphorus and sulphur, immediately tells on the quality of the pig iron produced. Zinc and lead are also harmful impurities, since they are disastrous to the lining and brickwork of the furnace. On the other hand, the impurities manganese, nickel, vanadium and copper improve the quality of pig iron.

To cut the long story short, no blast furnace will operate properly if it is fed with a run-of-the-mine ore, especially if the ore comes from different mines.

The first step in ore preparation is to average it for composition, that is, to mix the different kinds or grades of ore as much as possible. This is done in the ore stockyard. The ore arriving at the works in ships' holds or in railway wagons is unloaded by huge cranes called ore bridges. At first glance, it might look as if they are "milling the wind". Moving over an ore pile, each bridge grabs a bucketful of ore and spreads it in a thin sheet. This is how the ores from different deposits are mixed with each other.

The next step is to beneficiate the ore, or to make it more suitable for use in the blast furnace. Lumps the size of a fist or a bit smaller go to the stock house. The finer material is further treated in ball mills, huge rotating drums with heavy cast-iron balls rolling over in the inside. There, the fines are reduced to dust, and the dust is passed through magnetic separators. But
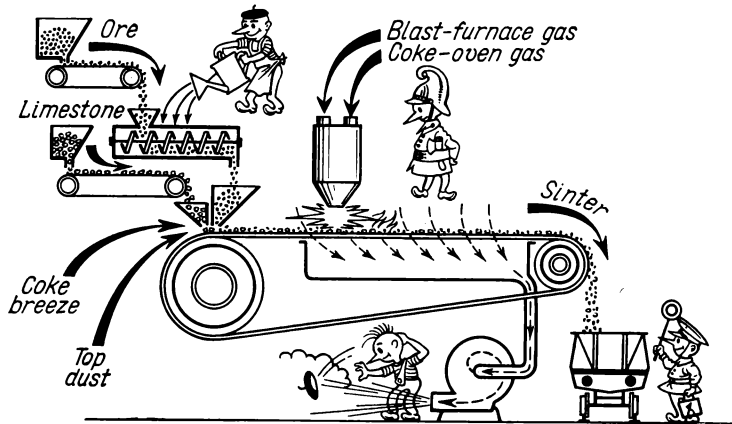
Making sinter for the blast furnace

the iron concentrate thus prepared cannot be charged into the furnace. If it were charged, the fines would be blown out of the furnace by the blast at once or would clog all the passages in the burden, and a scaffold might develop. So the fines are sintered before they go into the furnace.

Ordinarily, the ore-sinter plant is built around a travelling grate sintering machine. The machine is in fact a moving belt consisting of separate pallets on which the charge is fused into larger particles. The charge consists of the fine ore, top dust, coke breeze and limestone as flux. The travelling grate makes the bottom of the pallets, and beneath it there is a chamber where a constant vacuum is maintained. At one end of the machine the charge is dumped from hoppers onto the travelling grate, a burner fired with coke-oven and blast-furnace gas sets fire to the material, and the air is continuously drawn through the charge to keep it burning.

The charge grows white-hot and the material sinters. At the same time some of the sulphur in the ore burns out. The limestone is decomposed into a product suitable for use in the blast furnace. At the other end of the moving belt the sinter, a solid, grey-coloured porous material still red-hot, breaks off to fall onto a screen and into wagons.

It is this sinter mixed with graded ore lumps that goes to feed a modern blast furnace.

Why to go to such trouble over the ore, you may ask. Would it not be more profitable to devise better ways of controlling the furnace?

No, it would not. It has been calculated that an increase of as little as one part per hundred in the iron content of the ore charged into the blast furnace raises its efficiency by 2.5 per cent and cuts down coke consumption

by two per cent. Multiply these figures by the number of blast furnace in a big country like the Soviet Union and you will get the idea of the advantage. The gain in output and efficiency more than offsets the money and effort spent on ore beneficiation and sintering.

Next comes flux. Do you know that any ore contains materials which have melting points above the running temperature of the blast furnace? For example, alumina melts at 2050°C, while the maximum temperature of the blast furnace is 1800 to 1900°C. And there is as much as eight per cent of alumina in iron ores. How can it be removed from the furnace?

This is where flux comes in. The flux combines with the alumina and other high-melting-point materials to form compounds which melt at a much lower temperature and are, on top of that, very fluid when molten. What these compounds form is called slag. It is run off from the furnace at regular intervals.

The material used as flux depends on the smelting process used. Most often, it is limestone; sometimes it is dolomite; in a few cases open-hearth slag serves this purpose.

Now we have come to coke, a strong porous material that remains after some grades of coal have been suitably treated.

The reason for using coke and not coal in the blast furnace is this. The ore, flux and fuel charged into the furnace make up a stack of burden some thirty metres high. With the fuel usually placed at the bottom of the furnace, it must be strong enough to "shoulder" the burden lying above. Ordinary coals, even the best ranks of anthracite, won't do that. Nor are they porous enough to allow the free passage of gases through them. So, before it goes into the blast furnace, the coal must be turned to coke.

Not all coals will turn to coke. Nor is just any coke good for the blast furnace. The current practice is to make "metallurgical" coke out of a mixture of several ranks of coal. At the Zhdanov By-Product Coke Plant, the Ukraine, this is done as follows.

The coal arriving at the plant is of four ranks. Each rank goes to a storage bin of its own. Each bin is a tall tower as high as an eight-storeyed building. Out of the bins and through weigh hoppers, each rank of coal is discharged in accurately metered amounts onto a belt conveyor, making up a sort of four-ply "pie".

Then the "pie" goes through machines where it is mixed and ground. From these machines, the ground coal mix is charged into coke ovens.

Each coke oven is made up of a coking chamber where the mixture of coals is charged, and combustion flues where a suitable gas is burned.

The coking chamber is a narrow, long and tall slit, four and a half metres high, fifteen metres long, and not more than forty centimetres wide. Its walls are the "griddles" on which the coke "pie" is baked. If they were spaced wider apart, the "pie" would not be baked as thoroughly as it should be.

Coke ovens are built in batteries so arranged that each row of combustion flues heats half of two adjacent coking chambers.

The walls of the chambers are heated to 1000-1100°C, but the coal is not burned because it is kept out of contact with air. Instead, what is known as distillation takes place. The volatile matter of the coal is driven off, and the pieces of coal fuse together. It takes twelve to fourteen hours to turn a charge of coal into coke.

Then the doors of the coking chamber are opened by machine, and the coke is pushed out of it by a power operated ram, or pusher. The coke is quenched by a water spray and graded. Pieces about an inch across go to the blast furnace. Coke dust, or breeze, is used in the ore-sinter machine. The sizes in between are utilized in other departments. Coke grit goes to sprinkle pig iron in ladles to prevent a solid crust from forming in its surface.

The coke thus prepared is thoroughly analyzed in the laboratory. About 410 kilograms of it are charged into a drum, and the drum is rotated. A good grade of coke should remain intact after 150 revolutions, and not more than a specified amount of fines should be screened out of the drum. Sometimes, the coke may be analyzed for each of its constituents.

Such is the lengthy road coal has to cover before it becomes good for the blast furnace.

The blast furnace breathes, in goes air, and out comes blast-furnace gas. However, ordinary air such as we breathe is no good for it. It must be suitably prepared.

It is not an easy job to prepare the 3,500 cubic metres of air that the blast furnace uses every minute. The air in the Bolshoi Theatre in Moscow would be enough for the blast furnace to run for not more than ten minutes. Every hour it uses 270 tons of air, and during the day, 6,500 tons. If liquefied, this air would make six train-loads.

The air for the blast furnace is supplied by air blowers, which are huge fans. They draw in air and compress it to a pressure of 3 to 3.5 atmospheres. The air blowers are driven by steam turbines, each developing 14,000 horsepower. So it takes the power of a herd of 14,000 horses to drive the 6,500 tons of air through the blast furnace every day!

The compressed air is then heated to 800-1000°C. This is done in hot-blast stoves. Each stove is a huge tower, as big as the blast furnace itself.

It is filled with refractory checkerwork which takes up the greater part of the space inside the stove. The checkers serve as a sort of heat accumulators.

A hot-blast stove operates as follows. First, blast-furnace gas is burned in the part of the stove free from checkers. The violent flame rages in the combustion chamber.

The hot products of combustion roar through the checkers, heating them to 950°C or higher. When the checkers become that hot, the burner is turned off, and the air, or blast, for the furnace is passed in the opposite direction. The stove is then said to be "on blast". On passing through the checkers, the blast is raised to 800-900°C. As soon as the checkers have cooled to that temperature, the stove is changed back to "gas" for heating.

Because of this cycle of reversals, there should be three or even four hot-blast stoves to a furnace, one supplying the blast, another being heated, and the remaining shut-down for repair.

However, even within a single cycle, the temperature of the blast is continually decreasing. Since the furnace needs a blast of one and the same temperature throughout, several automatic valves have to be provided in the stoves. One of them, the cold blast valve, controls the amount of cold air let into the stove. The other, the hot blast valve, regulates the exit of the blast from the stove.

Over a century ago, it was thought that the furnace would "run smooth" on a colder blast. This opinion had come from the observation that in winter blast furnaces usually worked better. The established view, however, crumbled after early experiments. It was found that raising the blast temperature to 300°C would cut down fuel consumption by one third. At the same time, the rate and output of the furnace would be increased. The reason is simple. The heat of the coke is no longer spent on heating the air; instead, all of it goes to do useful work. So, the hotter the blast, the better the furnace runs. This is why blast-furnace operators have been seeking ever new ways of raising the temperature of the blast.

In recent years, they have come to use what looks like genuine air conditioning. They dry the blast and enrich it with oxygen and natural gas. The dry blast takes less heat to break up its water, and the addition of oxygen and natural gas cuts down coke consumption. Incidentally, more than half of the pig iron produced in the Soviet Union comes from blast furnaces fired with natural gas.

Now, the blast furnace not only eats or breathes. It also "drinks" for cooling. Whole rivers of water flow through the pipes in the bottom portion of the furnace and also cool the tuyeres that supply the blast.

It takes about twenty to twenty-five cubic metres of water to cool a furnace for every ton of pig iron tapped from it. This works out to 50,000

cubic metres circulated through the entire cooling system a day. The water would fill a large pond 100 metres square and five metres deep.

Such is the appetite of the present-day blast furnace. What does it then look like, this monster of brick and iron, topped by a crown of pipework and surrounded by a complex of services which prepare ore, flux, coke, air and water for it? What is going on in its fiery entrails where the main metal of human civilization is born?
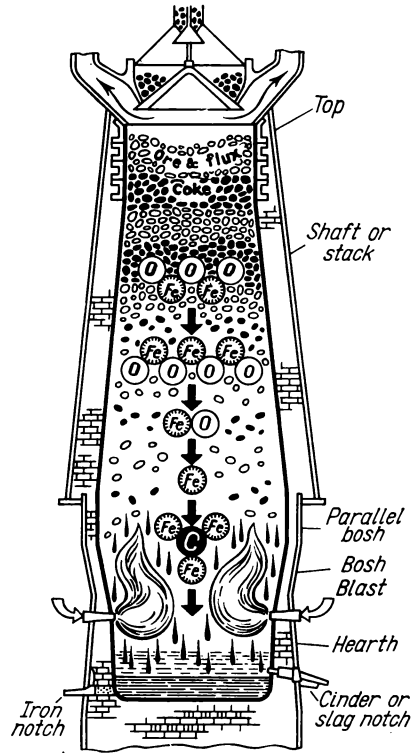
After they have been prepared in the way we have just learned, the ore, coke, and flux are automatically weighed out and dumped in proper proportions by a hoist in alternate layers into the furnace. The place where the charge is fed into the furnace is called the top. The top is closed by a device known as the double-bell-and-hopper. This device does three things at a time. Firstly, it spreads the charge uniformly all the way round the perimeter of the top. Secondly, it prevents the blast-furnace gas, a valuable combustible, from escaping into the air. Thirdly, it catches and channels this gas for recovery.

That's how miracles are worked in the blast furnace

As it moves down from the top, the charge comes in contact with the rising current of hot gases and undergoes a chain of transformations with the result that the ore is reduced to iron metal. Let us trace how this happens.

The first change that takes place is drying. The gas at the top, or simply top gas, has a temperature of 200 to 300°C. This is hot enough to drive off both hygroscopic water and the water of crystallization.

Just below the top begins the stack, or shaft, of the furnace. Its outward-flaring walls extend as far down as the parallel bosh, or belly, the widest part of the furnace. The belly and the inward-flaring bosh below it together make up the hottest part of the furnace.

As the charge moves down through the stack, belly and bosh, the furnace gases react with the iron oxides in the charge. The main part is played

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by carbon monoxide. It has the interesting property of taking oxygen away from the iron oxides to form carbon dioxide and to leave free iron behind.

Passing through a layer of ore where it takes away the oxygen, the carbon dioxide gets into a layer of coke just above. There is no oxygen in that layer, but plenty of coke. So each molecule of the carbon dioxide gives away the oxygen atom it has taken from the ore to the carbon atom coming from the coke, and changes back to carbon monoxide. In the next layer of ore above, this carbon monoxide again produces another atom of free iron.

Moving down and down, the ore loses more and more of its oxygen, and ever more free iron is produced. It is solid, and is called spongy iron. It need not be melted, so the charge is kept at 450 to 900°C. This new-born iron is very pure. It carries neither sulphur nor phosphorus, nor even carbon. Many an inventor has racked his brain over how to stop the smelting just there, before the free iron turns into iron-carbon alloy. But the charge keeps moving down, the iron picks up carbon, and the melting point falls off. So at 1250 to 1300°C, the first drops of molten metal come along. They trickle down to be collected in the bottom portion of the furnace, the hearth or crucible.

Spaced equally apart about the upper end of the hearth just below the bosh are the nozzles, or tuyeres, through which the blast is forced into the furnace. This is the hottest part of the furnace. The raging flame burns the carbon of the coke in the oxygen of the air.

The slag which begins to form at the top of the bosh also trickles down to the hearth. It is lighter than the iron and floats on the surface of the molten metal. So two layers are formed, a lower layer of metal and an upper layer of slag. The molten metal is drawn off through the tapping hole or iron notch, and the slag through the cinder notch.

This is, of course, only a bare outline of the things that happen in the blast furnace. The actual happenings are far more complicated. Indeed, even scientists have not yet learned everything about the blast-furnace process, and research continues.

Improvements are also being made in blast-furnace design and operation. Ever bigger furnaces are being built, operation under pressure has been tried and accepted, an ever hotter blast of various composition applied. Steady headway is being made in blast-furnace accessories and control. Some of the units have been put under computer control.

VALUABLE SLAG

The blast furnace has no wastes. All of its products can be put to some use. The hot cooling water discharged by the furnace goes to heat our homes and green houses; it is used in baths and laundries; underground irrigation

with hot water doubles and even trebles the yield of kitchen-garden crops.

Some five million cubic metres of blast furnace gas comes from each furnace over a year. Although every kilogram of blast furnace gas gives off only 850 to 1000 large calories, this is quite enough for many applications. True, before blast furnace gas may be put to some use, it must be cleaned of the dust it has carried off from the furnace. Sometimes, there is as much as 100 grams of flue dust in every cubic metre of gas.

There are several ways of cleaning blast-furnace gas. Primary cleaning is done in inertia dust catchers, commonly called cyclones. In a cyclone, the gas follows a spiral path, and centrifugal force throws the dust particles against the cyclone wall. The particles slow down and settle into a hopper. As little as two to five grams of dust is left in every cubic metre of gas coming out of a cyclone.

Further cleaning is done in scrubbers in which the gas passes over moistened surfaces or simply through sprays of water, and the dust is washed out of the gas. The last traces of dust may be removed either in electrical precipitators or in disintegrator cleaners. In an electrical precipitator, the gas gets in a strong electrostatic field, and the charged dust particles settle at an electrode. A disintegrator cleaner is a type of fan that dashes the water into a spray which travels in one direction, and the gas is forced in the opposite direction, so that the dust is also washed out. In the blast-furnace gas finally cleaned there is no more dust than in the air of your room. The dust caught in the gas cleaning plant is added to the charge of ore sintering machines.

As to the gas itself, we have already seen it fusing crushed ore in sintering machines, heating the checkers in hot-blast stoves and distilling coal in coke ovens. We are going to see it being mixed with coke gas, burning in open-hearth and reheating furnaces and driving the gas turbines of air blowers and electric generators.

We have called slag "valuable". And it is every bit so. In composition, it is similar to lava. Since it comes out of the furnace in the molten state, slag can be directly cast into a variety of products, such as stone blocks for pavements, acid-proof facing slabs, and pipes. And these can be manufactured at almost no cost. Just place a mould under the cinder notch and then take out the casting.

Blast-furnace slag makes a high grade of cement. For this, about seven to nine-tenths of slag is ground together with cement clinker. The product stands up well to the action of mineralized water and gives off very little heat on hardening. It is cheaper than any ordinary grade of cement, while it has nearly the same uses extending from the dams of hydro-electric power stations to the factory-made walls of houses. In a word, slag cement is a superb building material.

Few laymen have probably heard about slag wool. It is an excellent thermal-insulating material. Heating up to 600°C has no effect on it. Slag wool is very easy to make. A stream of molten slag is broken up by a current of air into thin jets which solidify into long threads.

There are also concrete, pumice and crushed stone that can be made from blast-furnace slag.

But the main product of the blast furnace is pig iron. The name "pig" has survived since the time when the molten metal from the furnace was cast from a main runner into smaller runners and depressions on one or both sides—a thing which looked like a sow with a litter of suckling pigs. Many blast furnaces today do not cast their iron into pigs any longer, but the name "pig" has stayed with us.

When the tapping time comes, a hole is made through the clay plug of the iron notch, and the white-hot jet of molten metal begins to flow out. In a moment the thin jet turns into a rivulet, and the rivulet into a broad, heat-breathing stream which flows through the runner into a locomotive-hauled ladle. Still liquid, the "hot metal", as it is called, goes to be converted into steel and made into harvesters and trucks, rails and bridges, girders and watch movements.

Before this can happen, however, pig iron has to cover a long road.

CONVERSION TO STEEL

Way back, iron was made by heating a mixture of ore and charcoal in a flat-bottom furnace, or forge, until a small body of pasty metal had collected, which was then drawn and hammered into wrought iron. It was soft, had almost no carbon, and was difficult to harden.

As the demand for iron grew, forges increased in size too. About the year 1350, the ironmakers of Central Europe came by a new type of furnace, built of masonry which enclosed a circular shaft. In a crude way, that was a genuine blast furnace, with air blown in at the bottom. Now the metal would melt in the furnace and permit of casting. That was pig iron. Unfortunately, it could not be forged and was weak and brittle. In that form it could be used only where strength was not of great importance. So ways and means had to be devised for converting pig iron into more suitable products—cast iron, wrought iron and steels. But steels came along much later.

Today, a greater part of pig iron is converted to steels. The conversion boils down to reducing the carbon content from four or five per cent to a
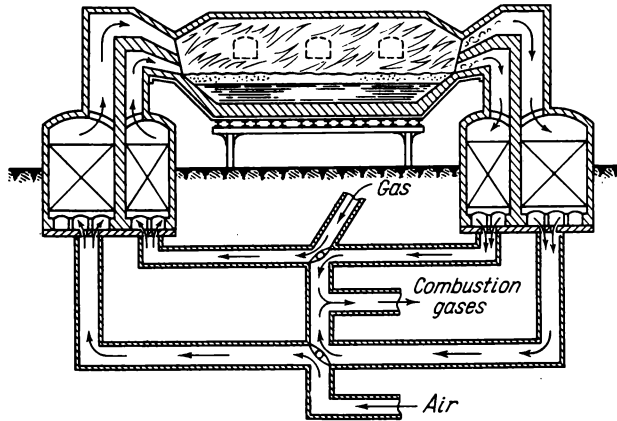
Making steel in an open-hearth furnace

few tenths or even hundredths of one per cent. Most often, this is done in open-hearth furnaces.

An open-hearth furnace looks like a huge iron box. On the inside it is lined with firebrick. Sometimes this box holding anywhere from 300 to 500 tons of metal is made tilting on trunnions fitted into huge pedestals.

It is always hot in the open-hearth department, both in winter when it may be forty degrees Celsius below zero outdoors, and especially in summer at thirty degrees above zero. The floor in the department is covered by cast-iron slabs. If you come up to the tiny peep-hole covered by a blue glass, you will see the white-hot surface of molten slag, slightly heaving under the air blast which makes ripples on it.

In the meantime, an adjacent furnace is being charged with steel scrap, cold pig iron, flux, and iron ore. The charge is put into a charging box. The long arm of a charging machine lifts and passes it into the furnace, turns it upside down to empty its contents, and withdraws it. In the same way the machine handles another box-load of charge, and then another, until the furnace has received its full share of charge. Now the furnace is heated up and finally hot pig iron is added from a hot-metal mixer.

A violent flame rages under the arched roof of the open-hearth furnace. Its temperature is 1700 to 1800°C, rising as high as 2000°C at the focus of combustion. The firebrick lining the roof, walls and hearth of the furnace

comes very near to its fusion point, and the operator, called the first helper, has to be on the alert all the time, lest the lining should run down in a sort of icicles.

Even today, for all the samples drawn every fifteen to twenty minutes and for all the carbometers and provers employed, the manufacture of steel is much of an art. The operator must have a good "feel" of all that is going on in the furnace. He must know when to "pig up" the charge, that is, to add more pig iron, in order to "block", or to keep constant, the carbon content; or when to "ore down" the charge for the opposite effect. He must know when to add enough of a proper flux to keep the slag fluid, when to run off primary slag and how to build up a fresh blanket of it. He must not miss the instant when to tap the steel.

By that moment, a huge steel ladle pulls up at the pouring side, and the steel flows out of the furnace through the tapping spout and into the ladle. The whole cycle of converting a charge of pig iron into steel, or a heat, as furnacemen call it, takes a few hours to complete.

Today about eighty per cent of all the steel produced in the world comes from open-hearth furnaces. However, the open-hearth process is not the only one possible.

BESSEMER VERSUS MARTIN

Before the open-hearth process was first used to smelt steel by Pierre Martin of France in 1865 in a gas-fired furnace developed by William Siemens in 1861, steel had been successfully made by a far simpler method, the Bessemer process. For all its simplicity and efficiency, however, it could not hold its ground against the powerful rival. There were several reasons for this.

There is no denying, the Bessemer process can turn out more steel in less time. Essentially, it consists in blowing air under pressure through a bath of molten metal. The metal is poured into a pear-shaped vessel, called a converter and constructed of proper refractory materials. The blast oxidizes in turn some of the iron, all of the silicon and manganese, and then the carbon. The process goes on at a very high rate. The metal boils and nearly explodes in the converter, and a dazzling white flame burns at the nose of the Bessemer vessel. After fifteen to twenty minutes of blowing, the steel is ready for pouring. The converter is tilted, and the quiet stream of metal fills the ladle. More important still, there is no fuel to burn, as with the open-hearth process. The charge of hot pig iron is heated by the burning of the impurities.

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On the other hand, the open-hearth process gives a better steel. Bessemer steel has much nitrogen dissolved in it—the air blown through it consists of four-fifths of nitrogen. The steel also has grains of iron oxides and air bubbles. It would be risky to use such steel in critical structures because they might break. In the open-hearth furnace, the action is less violent, and steel of practically any analysis can be produced. Another advantage is that the open-hearth furnace may use a fully solid charge—scrap, iron pigs and ore.

NEW LEASE OF LIFE

Yet, it would be wrong to say that the Bessemer converter is on its way out. It has been given a new lease of life in a modified form.

Reasoning that nitrogen was mainly responsible for the poor quality of Bessemer steel, researchers in many countries thought of using pure oxygen instead of the air blast. Thus, several oxygen steel-making techniques have come into use now combining the high-quality product of the open hearth with the speed of the Bessemer converter. Among them is the LD process invented in Austria. In the Soviet Union, a similar process was pioneered by the engineer Nikolai Mozgovoi at the Dynamo Works in Moscow in 1945. In 1956, his suit was followed at the Petrovsky Works and in 1958 at the Krivoi Rog Works, the Ukraine.

In addition to the oxygen blast, the two processes differ in several more things from the straight Bessemer process. For one, instead of an opening in the bottom, the blast is blown in through a water-cooled pipe, or lance, which runs vertically down from the top. Where the jet of oxygen strikes the metal, the temperature rises to 3000°C, which is hot enough to melt the most refractory metals molybdenum, tantalum and niobium. If the blast were blown in from below, the bottom would be quickly destroyed by such heat.

For another, blowing time is twenty to twenty-five minutes instead of fifteen when the air blast is used. This is because the blast has to be stopped several times to allow the metal to cool and the slag to separate out. Yet, a single 35-ton LD-converter turns out as much steel over a day as a 500-ton open-hearth furnace. The LD-converter completes fifty heats in the meantime, totalling 1,600 tons of steel, against the two heats, or 1,000 tons, of the open-hearth furnace. Also, an LD-converter is cheaper to build than an open-hearth furnace.

There are also rotary converters using an oxygen blast. A rotary converter looks very much like a concrete mixer. It has either one oxygen lance,

as in the Kaldo process from Sweden, or two lances, as in the Rotor process from Germany and the Soviet process introduced at the Nizhny Tagil Works, the Urals, in 1958.

Ore and limestone are charged into the rotary vessel while it is stationary from a suspended hopper. Then molten pig iron is poured from a ladle through the spout, and the lance (or lances) is inserted in the same opening.

Where two lances are used, one is dipped in the molten metal, and the other blows oxygen over the surface of the bath. The oxygen from the first lance breaks through the molten metal to combine with the carbon. The carbon monoxide escaping from the bath is burned to carbon dioxide by the oxygen from the other lance. The temperature in the vessel rises to 2000°C.

When the melting stage is well ahead, the operator cuts in the knife switch, and the vessel begins rotating. The rotation speeds up the process and improves the stirring action. As a result, almost all of the sulphur and phosphorus is eliminated. The stirring of the bath protects the lining from destruction by the high heat.

Blowing time is not over twenty minutes. The time per heat, from charging through flushing the slag to tapping the metal, is fifty minutes. So, twenty-four heats can be made a day.

The rotary converter is a still better performer than its LD counterpart. The blow can be stopped at any carbon content from five to eighty parts in ten thousand. In quality, the steel from the rotary converter is better than that from the LD process. The yield of good metal from the former is three per cent greater than from the latter, for which it is 84 per cent, and less oxygen goes to run a heat.

The rotary converter is a successful competitor with the open-hearth furnace as well. Ton for ton of the steel produced, the cost of a rotary converter is one-eighth of that of an open-hearth furnace. It takes very little floor space and almost no fuel, except what is necessary to heat it up after repair or a shut-down.

So, it seems besides the point to argue which of the two processes, Bessemer or open-hearth, is to stay with us. The chances are, both will continue, separately or combined, to improve in performance and steel quality. But both have a very dangerous rival—electric steel making.

STEEL BORN OF AN ARC

Metallurgists today have a very precise idea of how pig iron changes to steel, how slag affects the conversion, and which impurities and additions can produce what. In their opinion, it would be ideal to use a process in

which neither air nor products of fuel combustion are allowed to enter. Varying the amounts of additions, slags and impurities, they can make the best steel of any specified composition, they say.

Such a process is not something unattainable. As a matter of fact, it has been in use for about a century already. This is electric steel-making.

Arc furnaces for steel-making are no longer the small things they were in the past. Some of them are built in capacities up to 180 tons. They are complex units with sophisticated electrical and mechanical gear.

Briefly, an arc furnace operates as follows. First, it is charged (with solid material or hot metal, depending on the process used). Then current is turned on, and the graphite electrodes are pushed in. The current arcs from one electrode, is conducted through the charge and arcs back to the other electrode. The intense heat of the arc, which may be as high as 4000°C, melts the charge, drops of metal trickle down and are collected on the hearth.

In a melting-type furnace, the process stops just there. In a melting-and-refining furnace, flux is added to produce slag. In single refining, the same slag is used for both melting and refining. In double refining, the charge is molten and refined under a black slag which withdraws most of the phosphorus, hydrogen, nitrogen and other non-metallic inclusions from the steel. Then the black slag is flushed and a reducing or white slag is produced, under which refining is carried to completion.

There are many more steps in the process. It would be too much to trace them all. It is enough to say that each of them serves a purpose of its own and advances a common goal.

After five to eight hours, the steel is ready. It is of a quality unattainable by any other way. It contains just traces of phosphorus and sulphur, very little of non-metallic inclusions, and additions in the amounts precisely planned by the makers.

Some of the arc furnaces are of the refining type only. The charge for them comes either from an open-hearth furnace or from a Bessemer converter. Then we have a duplex process which takes three hours at the most to complete.

The steel manufactured in arc furnaces suffers from one major drawback —it is costly. It takes some 700 kilowatt-hours of electricity to make a ton of steel, and there are also the flux, electrodes and other expendable materials to pay for. Yet, electric steel-making is gaining ever more ground in the world production of this metal. In 1955, the United States produced 7.6 million tons, or 7.1 per cent of the total, in electric furnaces. In the same year, the Soviet Union made 3.4 million tons of electric-furnace steel, or 7.5 per cent of the total.

However modest its position may seem, the arc furnace is a powerful rival to the Bessemer converter and the open-hearth furnace. We shall not

stretch the point too much, if we say that the future of steel-making is with the electric furnace, unless metallurgy takes some sudden turn which will make both pig iron and its conversion to steel unnecessary.

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VACUUM AS A HELPER

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Now let us jump a little ahead and go to a ball-bearing factory. An automatic checking machine picks the balls one by one and examines them before the eyepiece of a photo-cell. The electronic quality inspector is exacting but just. It will not discard a good ball, but it will not pass a bad one unnoticed either.

We pick up a discarded ball. On its mirror-polished surface we can easily see some black specks or dots.

"Those are non-metallic inclusions," an expert will tell you.

No, this ball cannot be used in bearings, vitally important parts of any machine. So, the automatic inspector is right to have rejected it. But how could these specks possibly find their way into the metal prepared and machined with the utmost care?

They can do this in several ways. Firstly, they can get into the metal with the impurities present in the charge or flux additions. Secondly, these can be particles from the crumbled lining of the furnace or steel ladle. Thirdly, they can be the oxides of manganese, aluminium, calcium or titanium, added to the steel to "finish" it. Fourthly, they may be oxides and nitrides which owe their origin to the atmospheric oxygen and nitrogen.

How can one get rid of them or at least bring down their content?

The remedies are clear: to use a cleaner charge, to line the furnace and ladle more thoroughly, to pour metal quickly so as to cut down the time it is in contact with the air or, still better, to melt the metal in a vacuum.

Of course, it is no easy thing to put a hood over the electric furnace and the automatic or remote-operated teeming mechanism and to evacuate the air from beneath the hood. The more so that the pumping must be done all the time, because gases and fumes never stop escaping from the metal. Some of them were dissolved in the metal, others are formed by the chemical reactions during melting.

Yet, such furnaces do exist. They make the best grades of alloy steels and the alloys of titanium, chromium and some other metals especially sensitive to dissolved gases.

Sometimes, it is advantageous at least to teem steel under a vacuum. Then the steel ladle is placed under a vacuum, the dissolved gases separate out of the molten metal and so do many of the non-metallic inclusions which go over into slag. As a result, the steel improves in quality.

Now the heavy steel ladle holding a good hundred tons of metal majestically hovers at the ceiling of the casting bay.

"The steel is coming!" the people in the bay then say.

The crane stops the ladle over ingot moulds —huge box-like cast-iron vessels holding several tons of steel each. They are ready to receive the metal. On the inside, they have been thoroughly cleaned with steel-wire brushes, blown through with compressed air and coated with a mould wash. The white-hot metal fills the moulds.

Then the steel solidifies. It does so slowly. Its thermal conductivity, as we have learned, is one-tenth of copper's and one-sixth of aluminium's. It takes much time for the huge amount of heat given off on crystallization to pass through the already solid layers of metal.

Crystallization starts at the periphery, where the molten metal poured into the mould comes in contact with its walls. There, a multitude of tiny, haphazardly oriented crystals form to make up what is known as the skin of the ingot. From the skin, bigger and well-defined crystals extend towards the central portion of the ingot where they crowd all impurities. Since the metal contracts on solidifying, a cavity known as the pipe forms in the central portion, the area of weak and contaminated metal.

Various schemes have been tried for confining the pipe to the top of the ingot. Before the ingot goes in for rolling, the top is cropped and sent for re-melting. The bottom end of the ingot has also to be cropped and remelted. All in all, ten to fifteen tons out of a hundred have to be discarded and returned to the furnace for re-melting.

This is both costly and inconvenient. As a way out, a new method for ingot casting has been devised, known as continuous casting. It is gaining ever more ground at many steel works.

From the casting ladle the steel is poured into a tundish. In a way, the tundish is to molten steel what a hopper is to loose materials from which they are metered out in a continuous stream. The tundish meters out molten steel which flows into a mould. The mould of a continuous casting machine is a box of red copper. It has neither a top nor a bottom, but has double walls which make up a water jacket in which water is made to circulate. Instead of a bottom, a piece of steel, called the dummy bar, is placed in the mould.

As molten steel flows from the tundish into the mould, it comes in contact with the cold dummy bar and the copper walls of the mould. In an instant, a thin crust, or skin, is formed, and the dummy bar, on moving down, pulls the strand of metal along. On its way down, the skin of the strand grows into a thick shell strong enough to hold its contents as it leaves the mould.

At the outlet from the mould a rain of water droplets comes down on the white-hot shell, and the metal freezes throughout the strand. Then a gas cutter comes into action. Going down together with the strand of steel, its sharp flame cuts off billets about two metres long for rolling. The steel arms of a manipulator carefully pick them up and load them onto a conveyor. What was molten steel in the casting ladle a mere fifteen minutes ago is ready, as a billet, to be worked in a rolling mill.

The billet made by a continuous casting machine is different from the ingot coming out of a casting-pit mould. It has no pipe; no metal is wasted as a cropping discard; it will be rolled into a channel, rail or angle iron several times quicker than a billet cast by the conventional method. In fact, rolling can be done away with altogether. The mould of the continuous machine may be given practically any shape, that of a channel, angle, and so on, as long as the metal is good for it.

The Soviet engineer Myasoyedov has developed a continuous pipe-casting machine which operates on the same principle. The mould consists of an outer and an inner shell. The inner shell is inserted from above and is water-cooled. The rest of the process is as before. Although designed for cast-iron pipes, the Myasoyedov unit can cast equally well pipes from steel, copper, brass and so on. The underlying principle holds with any metal.

The continuous casting machine is the outcome of much effort. Thousands of trials had been made before the first strand of good quality came out of it. That happened at the Krasnoye Sormovo Works in May 1955.

Although their number was growing all the time, the early casting machines were not smoothly operating things. To begin with, they were very slow. The strand came out of the mould at a rate of about one metre per minute. In a word, continuous casting was in its infancy.

In May 1965, newspapers brought the news that the Novo-Lipetsk Works was installing continuous casting machines ganged with Bessemer converters into a single, integrated process. Surely, this speaks of the maturity of the continuous casting method.

A TURNPIKE FOR STEEL

I bet you will not overlook this machine. Alone, it occupies a building almost half a kilometre long. Its main motor develops five to seven thousand horsepower, and it totals three to four thousand tons in weight.

The machine is the blooming mill. It is a sort of turnpike through which all steel to be rolled has to pass. Almost everything made of steel in your home has gone through it.

The idea of the rolling mill is simple. The key parts are rolls, sometimes one metre in diameter. The rolls have grooves cut into their surfaces. The grooves of two rolls, one above and the other below, make up a pass through which the ingot to be rolled travels. The top roll is adjustable; it can be raised and lowered so that the two can be brought closer together or farther apart. Leading to and from the rolls are roll tables for handling the material. The mill is controlled by two operators from a raised platform in front of it.

An ingot, a rectangular block of metal some two metres long, weighing from five to eight tons and heated to 1100-1220°, emerges from a reheating furnace, shooting sparks in all directions. The feed-in roll table scoops up the ingot and carries it to the mill. The rolls start rotating, and the ingot is gripped in the broadest pass. Like a piece of clay in a child's hands, the metal is worked by the iron palms of the mill. Again sparks fly all over the place, and the ingot comes out at the other end, reduced a little in cross-section. The run-out roll table catches it up and carries it away from the rolls.

But the mill has not yet done its job. All of a sudden, the run-out table reverses and feeds the ingot back between the rolls. The rolls have by this time moved closer to each other, and the metal has now to go through a smaller pass. And again the metal is reduced in cross-section. This is repeated several times. The ingot is turned over from side to side by the tipper, until it is given the desired section, which may be round, square or rectangular. Now it is called a bloom, if of square or rectangular section and more than six inches on the side. There may also be round or shape blooms, though. Sometimes, it will be a billet, also of square or rectangular section and not more than six inches on the side. Or it may be a slab, if rectangular in section and with a cross-section of sixteen square inches or more.

Now, the ingot has been given its final form, whatever it may be. The run-out table carries it, many times as long as it was before rolling, to the opposite end of the mill. There, huge shears crop off the ends which are sent back for re-melting, and the remainder is cut to specified weights or lengths.

The mill operator would hardly cope with his task, if he were to turn on and off all the mill mechanisms all by himself. Fortunately enough, the mechanical mammoth is well automated. What the operator has to do is only to "program" the desired sequence of operations: so many passes through the rolls, so great a distance between the rolls for each reduction, when to turn over the ingot, and what pass to use. The actual supervision and control lies with automatic controllers.

Photo-cells keep constant watch on the ingot while it is being rolled. As an ingot comes out of the reheating furnace and reaches the feed-in roll table, photo-cells start it to run towards the main stand of the mill. When

the ingot comes out of the rolls, other photo-cells reverse the run-out table. And all this is done without a hitch.

From the blooming mill the metal goes to smaller mills. They turn blooms into rails, channels, I- and H-beams and other sections and shapes, so valued in mechanical engineering.

That is how iron and steel reach their user. We have traced them going through three stages.

In the first stage, iron is born in the volcanic shaft of the blast furnace out of ore. Unfortunately, the alloy of iron and carbon coming out of it is good for very few uses. Therefore, the metal goes to the second stage — conversion to steel.

We have listed three fundamental processes of converting pig iron into steel: open-hearth, Bessemer, and electric-furnace. But again, cast steel has limited use as such. That is why there is the third stage — the rolling of ingots into sections and shapes.

But is it not too long a road for metal to become a useful thing — a rail, a wheel, or a plough?

LOOKING FOR A SHORT-CUT

At all times metallurgists have been looking for better and shorter ways of turning the rusty-brown lumps of ore into lustrous metal, and they have done much. Still, there is room for further improvements. Looming large in many plans is the idea of fully automated iron and steel works where man will be unnecessary. Everything there will be run by an electronic "brain", a computer: the hoppers batching out the charge for the blast furnace, the furnace itself, the jeweler's art of steel-making, and the rolling of shapes. To supervise the whole thing, there will be one or, perhaps, two human operators, not more.

Are such plans feasible? Yes, they are. Will they be realized soon? No, of course not. In fact, it may so happen that the need for them will cease to exist before they are built. The point is that metallurgists have since long been playing with the idea of making steel in one stage instead of three. Thousands of such plans have been suggested to date.

At first glance, it does seem simple to make steel of the desired composition directly in the blast furnace. One might reason like this: pig iron collects at the bottom of the furnace; what if an opening were made in the bottom and oxygen blown through the molten iron some fifteen minutes before tapping, so as to burn all the carbon right in the furnace and to pour low-carbon steel into the ladle?

Although no one has ever attempted the thing, we may say nothing would come out of the idea, in all probability. It is not only that the vio-

lent flame, such as rages at the nose of a Bessemer converter, would upset the run of the furnace. More important still, there is so much carbon in the blast furnace that you just cannot get rid of it there.

Yet, there are direct processes for making iron from ore. Already ancient masters were using them. And their know-how has not been lost. Even today the Sulinsk Works in the Soviet Union smelts small amounts of sponge iron for special applications. Crucibles, or pots, made of fireclay, are charged with alternate layers of iron ore, coal and limestone and placed in a kiln where they are heated to about 1000-1100°C. At that temperature, as we know, neither iron nor gangue can melt. But during the fifty or sixty hours of "near-melting" or fusion, all of the iron is reduced, and it is removed from the pot as a round, porous cake, or sponge iron. It needs hammering, but it is pure, and not pig, iron. Although too slow and uneconomical to replace the three-stage indirect process, this process suggests a line of attack on the problem.

In another process, which in the Soviet Union was first used at the Orsk-Khalilovo Works, finely divided ore, flux and coal are charged into an inclined rotary kiln at its raised end. At the lower end, there is a burner fired with pulverized coal or gas. As the kiln rotates, the charge slides down, and the hot products of combustion, with a temperature of 1200 to 1300°C at the burner, rise counter-currently to it.

At that temperature, the gangue is fluxed into a dense and slow mass and the reduced iron is fused into balls with a good proportion of slag. The mixture is then cooled with water, crushed and sorted out by magnetic separation. One kiln produces as much as thirty-five thousand tons of wrought iron a year. But, again, the process is not economical enough to be a successful rival to existing indirect methods. Yet, it suggests still another line of attack on the problem.

A better approach is probably to roast ore in a fluidized bed. Although it has been used in non-ferrous metallurgy for about thirty years already, the fluidization process is just coming into use in steel-making. Its main features are as follows.

Picture to yourself a large vessel with a great number of holes in its bottom through which air is blown in continuously. If you now pour some flour, sand or dust into the vessel, the blast will keep the grains of the charge as if suspended in the midair, thus bringing the charge into a state resembling the boiling of a liquid. In the fluidized bed each particle is constantly blown over with air, and many chemical reactions proceed at a high rate and to completion.

Now imagine that instead of dust or sand, your vessel, or fluid-bed reactor, holds finely divided iron ore and the blast is a current of reducing gases. Then, the reaction going on in the vessel will be that of reducing the iron oxides of the ore to metallic iron.

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Now set up the reactor with its bottom sloping towards one end. Charge ground ore at the raised end, and let the mixture of iron particles and gangue drop onto the belt of a magnetic separator at the other. What you now have is a model of the fluid-bed reactor for the direct production of iron. It is going through laboratory trials, and there is enough reason to hope they will be successful.

But the quest for other direct processes of iron production continues. This is what Academician Bardin told the author one day:

"We metallurgists are not at all happy about the present-day method of making iron and steel. I do not see any reason why we should not drop from this process all intermediate steps which take so much energy, labour and money, so that pure iron or a steel of specified composition can be obtained directly from ore and in the finished form, such as rails, channels or girders. Nor can I see any reason why the process which is intermittent today (you first prepare ore, then you melt pig iron, next you convert it into steel, and so on) should not be made continuous.

"As I believe, all this is quite feasible, and the metal-making of the future will abandon the processes of today, including the blast and open-hearth furnaces, the Bessemer converter, the blooming and slabbing mills.

"This is not to say that in about a decade from now all blast furnaces will be pulled down to be replaced by reactors for the direct production of iron. No, that won't happen. The blast-furnace process still has room for improvement, and we shall continue to build blast furnaces for a long time to come yet. Already sophisticated to a high degree, the blast furnace of tomorrow will be a fully automated unit run by a computer which will be able to adapt itself and the furnace to any contingency.

"Before long, iron and steel making will be a continuous process. The blast furnace will deliver an uninterrupted stream of pig iron (in fact, there are blast furnaces which turn out over a ton of pig iron every minute already today). A current of oxygen blown through the hot metal as it flows out of the furnace will burn out excess carbon, sulphur and phosphorus — all that impairs the quality of the metal, carrying them off with the dazzling flame which will rise above the molten bath. Instead of a pig casting machine, there will be a continuous ingot casting unit making steel ingots. The ingots will be directly fed into rolling mills to be made into whatever products may be required. Such a continuous process will be much easier to automate than the intermittent one of today.

"It is not unlikely that some time in the future radical changes will take place in the design of the blast furnace. Iron will be reduced from ore to the metallic state in a huge rotating horizontal tube. It will be charged with a well-cleaned powdered ore, iron oxides without any impurities, at one end, and with a reducing gas, such as hydrogen, at the other. The iron will be produced as a fine powder to be smelted or pressed and sintered."

4

STRENGTH

Sometimes it happens this way. You look at the latticework of a bridge boldly spanning a gorge some three hundred metres deep, and the sight takes your breath away. The pillars are spaced widely apart, and the steel girders give out a ringing sound under tension. The mere thought of walking its planks singing in the wind makes you shudder. But heavy trains quietly cross the bridge which sags only slightly under the load. It will not break down under a weight three times as heavy. It has a good margin of strength.

Or you look at a supersonic plane droning in the sky. If you ask the pilot, he will tell you how strained every part of his plane is in flight. The air, so caressing when you ride a bicycle, becomes nearly solid as speed approaches that of sound. It tries to break off the wings and crush the fuselage of the daring bird of metal which has ventured to challenge air itself. Invisible but dangerous whirlpools make vain attempts to set off vibrations and to tear the plane to pieces. But the pilot is not scared a bit—he knows his plane has a good margin of strength.

Sometimes it happens the other way round. You look at a mammoth steam turbine and cannot believe your eyes. Its body is a writhing knot of tortured metal. The bolts which seemed to have anchored the turbine

to the concrete rock of foundation for ever are shorn off as if with a razor. Some parts are scattered all over the turbine house, others have been hurled through the windows. This has happened because there was not enough strength in the turbine.

In the history of engineering, there have been quite a number of collapsed bridges, buildings, oil storage tanks and hangars. In many cases, the cause of the failure has been lack of strength in the metal.

So strength is a vital property of any metal of construction. Bronze ousted stone because of superior strength. Iron crowded out bronze for the same reason.

At all times, the effort to get more metal has been accompanied by the effort to get a stronger metal. And today, man has got something to show for it. Indeed, many of the machines which have become part and parcel of our everyday life would be impossible to build if their designers were to use only the metals and alloys that existed a mere fifty years ago. We should have then to part with powerful steam turbines whose blades have to stand up to huge inertial forces, with high-pressure, high-temperature steam boilers whose tubes are heated almost to a cherry heat; with tall buildings whose framework has to bear monstrous loads; with supersonic jets and space probes; with many more things, in fact.

Even the car would be impossible to build with the materials the designer had at his disposal at the turn of the century. Or, if it were built, and with the same margin of strength as the modern car has, the vehicle would weigh about five tons. That would be a heavy and awkward thing to drive.

Man has not reached a limit to the strength of metals yet. People in the 21st century will wonder at how their ancestors in the 20th century were able to conquer the air and outer space with what will look like weak metals to them. They will calculate how awkward their machines would be, if built from the materials we are using today.

A TEST FOR STRENGTH

What is strength then?

As the story goes, when Bessemer cast his first ingot from the metal blown in his converter, he took an ax and struck three times at the still hot block of metal. The hardened blade cut deep into the soft and yielding iron. Bessemer nearly shouted with joy: the test he had just made had proved the metal blown from pig iron was soft steel.

Today, his test would not be enough. Metal-makers have at their disposal large laboratories, machines and techniques to determine the mechanical properties of metals, including their strength and durability.

Some machines pull specimens like a rope until they break. Others squeeze iron or steel bars between their "palms" until they collapse. Still others strike rapid blows at specimens, or now load and now unload them for weeks or even months on end, doing so at the rate of thousands of times every minute, waiting for the metal to show signs of fatigue. There are machines which keep a specimen, heated to a red heat, loaded for weeks.

Scientists have devised a large variety of tests so as to determine the quality and potentialities of metals as accurately as possible. The most commonly used and important is the tensile test. The test is carried out in a tensile testing machine and on specimens of standard shape and dimensions. A specimen is clamped in the grips of the machine, and the load on it is gradually increased. As the load increases, the specimen elongates. The elongation is plotted on a chart by a recorder. From the curve, known as the stress-strain diagram, the expert can readily tell how much elongation (or strain) has been produced by any tensile load (or stress).

Let us trace the curve for ourselves. Our test specimen is made of steel. The operator measures it to make sure it is of standard size, and clamps it in the grips. Then he cuts in the knife switch, the electric motor goes humming, and an ever increasing load pulls the specimen. In a moment, the stylus of the recorder starts tracing out a curve.

At first this is a straight line, because the specimen elongates in direct proportion to the increase in the load. In testing parlance, it is said that the stress and the strain are proportional. Up and up goes the stylus, crossing the chart at an angle, a bit to the right. Suddenly the curve makes a smooth turn, or knee, and changes into a straight line which now runs parallel to, and not across, the chart. From this we learn that the specimen "stretches" or "gives", marking an increase in strain without any increase in stress.

Find the point on the curve, at the beginning of the knee. At this point (A), the stress and strain cease to be proportional, and the point is rightly called the proportional limit. Sometimes it is referred to as the proportional elastic limit. Up to this point, our specimen remains elastic, that is, capable of recovering its original form when unloaded. If we remove the load anywhere up to this point, the stylus will re-trace the curve and the specimen will recover the same shape and dimensions as before the test. The strain within this region is called elastic deformation. The stress can only slightly dislodge the atoms in the crystal lattice, and they go back to their sites as soon as the stress is removed.

If we remove the load from the specimen past the proportional limit, say at the point B, the stylus will fail to re-trace the same curve. Instead, it will draw a straight line parallel to the curve of proportional elongation. In other words, when unloaded, the specimen will fail to recover its original length—it will be a bit longer. This increase in length is termed the
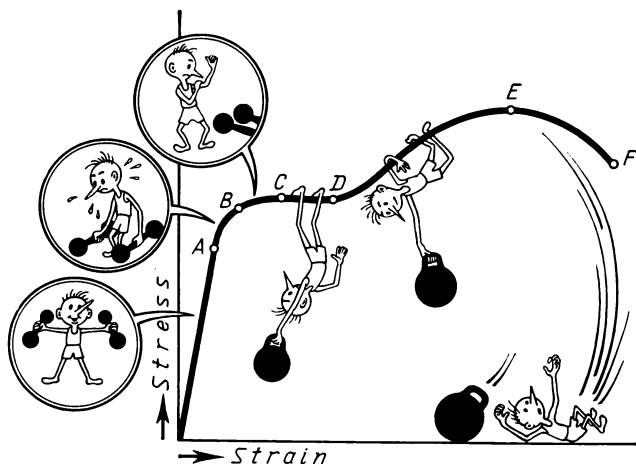
Stress and strain in steel

permanent set and is as great as the elongation the specimen undergoes past the proportional limit.

Of special interest is that part of the curve (between the points C and D) where the specimen "stretches" or "gives". Here, the strain increases while the stress remains the same. This is the region of yield, as engineers call it. It seems as if the metal has lost all strength and is no longer able to resist the load. This goes on until the metal, as if ashamed of its weakness, pulls itself together and finds new strength to resist the increasing load. The curve traced out by the stylus again turns up (the points D and E), at first steeply and then more gradually.

Now look at the specimen. It is having a hard time indeed. A neck appears on its once smooth surface. The elongation rapidly increases, although the load does not. Finally, the curve reaches the highest point and drops off. Then a crackling sound, like a pistol's report, indicates that the specimen has broken apart (point E). It has done so exactly at the necking. That brings us to the end of the test.

The operator takes down the values of the proportional limit, the yield point, and the tensile or ultimate strength, i.e., the maximum stress that the specimen can withstand. Then he measures the two broken parts of the specimen in order to determine the per cent elongation. All of these data are entered in the certificate of the metal under test. Their knowledge is very important to designers who plan to use it in machines or structures. Such "certificates" can be found in any reference book on metals. The fig-

ures there are averages of many tests, and the stresses are given, divided by the respective area of the specimen in square millimetres or centimetres (where the metric system is used).

Not every metal or alloy behaves like the steel in our test. If we tested a copper specimen, the line of proportional elongation would be not so steep, that is, a smaller stress would produce a greater strain. There would be no horizontal section corresponding to the yield point. A cast-iron specimen would fail very soon past the elastic limit.

In a word, the stress-strain diagrams are as different as are the metals themselves. Bend a safety razor blade and then let it go—it will uncoil with a ringing sound, showing no trace of permanent set. Aluminium or copper wire will obediently take any form you may happen to give it. You can hardly break a steel wire, but you will do so easily if it is of copper.

METALS WORK, GROW TIRED, CREEP

Of course, the tensile test alone cannot show all the potentialities of a metal. Cast iron, so weak when it has to work in tension, offers a high resistance to compression. This is the reason why a whole range of tests have to be carried out before everything becomes clear about the mechanical properties of a material.

For all the variety of stresses that machine parts and structural elements have to stand up to in service, they can be reduced to a few simple ones. Here they are:

The first and most important is tensile stress. To get a better idea of how it works, picture to yourself a suspension bridge. Its roadway is suspended from ropes, chains or wire cables extending between steel or masonry towers or other supports. Whatever the type of suspension, it is put under tension by the weight of the roadway. The suspension is said to work in tension. On the other hand, the towers or supports work in compression. Compressive stress is the second important type of stress.

Compressive stress is at work in the foundations of houses and machines, in the pillars of bridges and frameworks. In fact, it is not easy to say which of two stresses—tensile and compressive—is more common in engineering practice.

Next comes shearing stress. It is produced by forces which tend to slide one particle of a material upon another. It is demonstrated most graphically by an iron sheet cut by shears.

Those are three elementary stresses. All others are simply their combinations coming from arrangements of the external forces. Such is bending stress. It is at work in a beam supported at two ends, in the boom of a crane,

or in the wings of a plane. There is compressive stress on one side of the beam, boom or wing, and tensile on the other, with shearing stress existing throughout the part.

A part's work in bending differs from that in tension or compression. In the case of tension or compression, all of the cross-sectional area of the part bears the grunt. In bending, there is always a neutral portion which remains almost unloaded. You can take it out, but the strength of the part will be reduced very little, if at all.

Then there is torsional stress in which shearing, compressive and tensile stresses are all combined. The part as a whole is twisted like a piece of linen being wrung dry after washing.

Torsion is a very common type of stress. It occurs in shafts, axles and many other machine elements. As with bending, there is, in a part working in torsion, a central portion next to the axis of rotation, which remains little loaded. Farther from the axis of rotation, the load on the material increases. Incidentally, a tube will work more efficiently in torsion than a solid bar of the same weight.

Those are all static stresses, with the load applied gradually. But there are also dynamic or impact stresses where the load is applied as a blow. When the air-petrol mixture burns in a car engine, the piston receives a blow. The blow is transmitted to the connecting rod. From the connecting rod the impact is "relayed" to the crankshaft, and so on. Even the ticking of your watch is a series of impacts. Of course, if both the car engine and the watch are to be designed properly, their designers should know how metals stand up to impact stresses.

Static stresses are measured in kilograms per unit area. Dynamic stresses, which act instantaneously, are often measured in terms of the kinetic energy spent on an impact, or the work done.

Brittle materials usually have a low resistance to impacts. Quite the opposite is true of plastic materials.

As a proof, take two pieces of fine steel wire, one short and the other three times as long. Tie the shorter wire to a nail or a door knob, loop the other end around a stick so you can conveniently grasp it between your fingers, and pull it suddenly to break the wire. Now break the longer wire in the same way. You will have noticed the difference in the force you have to use. The longer wire is more difficult to break, as it "springs" and cushions the pull.

However, a metal part can be destroyed not only by a static stress which exceeds its ultimate tensile strength, or by an impact of a certain energy. It can be destroyed by a load which is repeatedly applied and removed, although the load itself may be not so great. The stress due to a repeatedly applied load is called fatigue stress. It often occurs in engineering practice. In a steam turbine, for example, the jets of steam coming

out of the nozzles strike at the blades, and the blades vibrate, making up to 200,000 such vibrations, or cycles, every minute. The maximum stress they produce is well below the ultimate strength, and the time during which it acts is very short. Yet, because of long repetition, it proves large enough to destroy the metal.

The ability of a metal to withstand such stresses is called its endurance. Experience has shown that there is a limit to the endurance of cast iron and steel. Also termed "fatigue strength", the endurance limit is scientifically defined as the stress below which the material will stand up to any number of stress cycles without breaking. A stress above the endurance limit will cause a part to fail in, say, fifty million cycles, while a still greater stress will do this in four million, and so on.

And again, knowledge of the fatigue strength of metals is very important, because fatigue stresses are inavoidable in a great many machine elements, such as locomotive shafts, the crankshafts of car engines, and chassis springs.

Destruction due to such stresses is called fatigue failure. It looks as if the metal grows tired of resisting the "irksome" loads and gives in. Experts call fatigue failures "progressive" because they start at some point and spread through the material. Such a starting point may be an incidental scratch, nick, crack, or cutting-tool mark. Any of them may serve as a local stress concentrator, or stress raiser. With each cycle the crack propagates further until the unaffected area becomes too small to resist the recurring stress, and the part breaks. Usually this occurs unexpectedly, because you cannot possibly see a hidden crack spread further and further.

The fatigue strength is usually a half to a third of a metal's ultimate strength. Sometimes, it may be well below its yield point.

Although the fatigue strength of a material depends to a great extent on its properties, its surface finish also affects it. A roughly machined part will have a lower fatigue strength than a part of the same material, but well ground or polished. The reason is simple—fatigue failure starts at a stress raiser; if there is none, the failure, if any, will occur at a much greater stress.

Now we have come to still another vital property of metals—their creep strength. It took up special importance when boilers and turbines had come to operate on steam of ever increasing pressure and temperature.

At first, a boiler or a turbine would operate trouble-free. Then it would fail. The high-pressure piping would burst first, followed by the turbine blades nearly scraping at the body because they had grown in length. That was most striking of all, for the load on them had never risen above the proportional limit. It was at that time that the word "creep" came into use.

As has been found, when stressed at high temperatures, any metal stretches continuously and progressively. Since metals soften on heating,

their strength goes down as temperature rises, and they fail under a smaller load when hot than when cold.

Metals, it is true, creep at a very slow rate. A rod of carbon steel one metre long will elongate as little as fifteen millimetres a year when subjected to a load of 100 kilograms per square centimetre at a temperature of 540°C. But this is more than enough to cause damage or even a breakdown to a steam turbine. The more so that a small increase in temperature, say to 600°C, speeds up the creep nearly ten-fold.

Creep occurs differently with different metals. Some begin to creep at a higher temperature, others at a lower one. Since most machine parts have to operate at elevated temperatures, it is clear that the designer cannot possibly do without a knowledge of the creep properties of metals. This is why metals are also tested for the creep limit.

Now let us go to a design office to see how a designer takes his pick of the metals. We come to find him thinking over the bedframe of a turbine. It must be strong enough to bear the load. At the same time, it must be substantial to ensure stability. So the material must be cheap. Which metal fits in best?

The designer consults his reference books which give the characteristics of metals. Steel could well serve the purpose. One of the steel grades has an allowable compressive stress of 1500 kilograms per square centimetre. However, cast iron, which is much cheaper, can also stand up to this stress. So he chooses cast iron.

Now he goes over to the turbine blades. With the turbine making some three thousand revolutions every minute, a crippling centrifugal force will work on the blades, tending to uproot them. From his slide-rule, that simple but efficient instrument, the designer learns that the force will be about four thousand kilograms per square centimetre to which should be added the impact of the steam jets. Besides, the blades will be in contact with the damp atmosphere of condensing steam. So it is important that the blades should not rust. The designer leafs through his books again, looking for a steel which would resist corrosion.

He runs into a good deal of trouble over the parts that are to work at a temperature of about 800°C. His first thought is to cool them with a current of air or a stream of water in pipes. But that would help little. Finally he decides that the thermal brunt should be borne by the metalwork itself. He opens a chapter on heat-resistant alloys. There he learns how the alloys behave not only at room temperature, but at 300, 600 and 800°C.

At last, after all this trouble, the design of the turbine is ready. The fine, tentative lines drawn in hard pencil, easy to erase and re-draw, give

way to heavy lines in a soft one. A table in a corner of the drawing gives a list of parts and the grades of metals they must be made of. It is only if makers follow his advice that the designer guarantees full strength for the turbine.

ADDITIONS THAT IMPROVE

In a German book published in the year 1546 there is an engraving which shows six young men on their knees before a majestic old man on a throne. The caption reads: "Six younger brothers are imploring their elder brother Gold to share his accomplishments with them."

To a 20th-century engineer gold offers no particular advantages over other metals except its chemical stability and ability to resist corrosion, or rust. And even this property has ceased to be the privilege of gold.

Gold does not measure up to many metals in strength. Add to this its heavy weight, and you would hardly call it a good structural material.

Not that this circumstance leaves the designer nonplused. Today he has a whole gamut of remarkable materials of construction to choose from. Among them are more than a thousand of alloys good for the most diverse services.

The pride of place goes, of course, to steels. Most machines, structures, and metal household things are made of steels. Today, there are hundreds or even thousands of steel grades.

Some of them came to our notice when we were discussing the constitution diagram of the iron-carbon alloys. In addition to carbon, they contain some impurities. Depending on their percentage, there may be low-, medium- and high-quality steels. A low-quality grade of steel may have as much as fifty-five parts sulphur in a hundred thousand. In a medium-quality steel, sulphur may account for thirty to forty-five parts in a hundred thousand. A high-quality, or low-metalloid, steel carries not more than two parts sulphur in ten thousand. Ordinarily, it is made in an electric furnace.

Carbon steels have very many uses. They are made into tools, machine parts, springs, engine cylinders, and kitchen utensils. For all their diversity, however, carbon steels cannot sometimes satisfy the designer. This is where alloy steels come in.

The name "alloy steel" goes for steels which, in addition to carbon, contain some other elements added to modify the properties of the metal. Such additions are called "alloying" ones.

We have already learned how impurities, even in very small amounts, can spoil a metal. It is for this reason that so much effort is put into mak-

ing germanium, antimony and other metals ever purer. In them, foreign elements degrade the parent metal.

The situation is altogether different with alloying additions. Sometimes, they give carbon steels such properties as could not exist in them otherwise.

Thus, carbon steels rust. That is a very unpleasant quality. Sometimes you just cannot protect the metal from corrosion. How can you possibly do so if the plating of a ship's hull is always in sea water? Or if the blades of a pump have to handle an aggressive liquid? Grudgingly, you begin to think of gold.

But the problem is easily solved by alloying. In effect, there is a whole class of corrosion-resistant, or stainless, steels made commercially. This property, once a privilege of gold, is secured in a steel by additions of nickel and chromium.

A steel containing twelve to fourteen parts chromium in a hundred will show not a single trace of rust after a few years' exposure to rain or snow. This steel goes to make surgical instruments which remain bright and untarnished from use for years. A steel containing twenty-seven to thirty parts chromium in a hundred can stand up to the action of both air and river water. Unfortunately, it is no good in sea water. Therefore, the components that are to come in contact with sea water are made of a steel containing eighteen parts chromium and eight parts nickel in a hundred.

Alloying elements can give steels properties which are non-existent in gold. For example, gold heavily wears from use. At one time, it was a big problem to keep gold coins from losing their weight. As gold coins changed hands, they inevitably lost some of their metal as invisible specks, and with it—their value, for their buying power exactly corresponds to the quantity of gold they carry.

Caterpillar tracks, railway points and crossovers would not last long if made from such a metal. Nor would plain carbon steel do, although it is many times as resistant to wear and abrasion as gold is. Instead, use is made of special grades of steel containing from eleven to fourteen parts manganese in a hundred.

Further increase in the pressure and temperature of steam in the boilers of power generating plants is handicapped by the lack of steels good enough for this service. Metallurgists have been going any length to make such steels. To improve resistance to oxidation, they add silicon. As much as over two parts silicon on top of six parts chromium in a hundred makes steel resistant to oxidation at up to 800°C. A grade containing three and a half parts silicon in a hundred will resist oxidation at up to 1000°C. Steels with about thirty parts chromium in a hundred resist oxidation at up to 1100°C.

The ability to resist creep and fatigue at high temperature is bolstered by additions of molybdenum and chromium. Sometimes, the goal is a steel resistant to oxidation, creep and fatigue at one and the same time. Then several alloying elements are added. One such grade contains about three-tenths of one part carbon, eighteen parts chromium, twenty-five parts nickel, and two parts silicon in a hundred.

Now alloying has been extended to include cast irons. The improvement in properties is so marked that some cast irons are beginning to vie with or even crowd out certain steels.

Non-ferrous metals also come in for this sort of treatment. Aluminium-base alloys contain silicon, copper, manganese, nickel, chromium, cobalt and zinc; copper-base alloys carry zinc, tin, lead, aluminium, manganese, iron, nickel and beryllium. Magnesium gets along well with additions of aluminium and zinc, and lead with additions of tin, antimony and zinc.

No, the junior metals from the medieval engraving are no longer beseeching their elder brother gold to share its accomplishments. In fact, they have gone it one better. Through friendly cooperation, they double each other's strength, as it were.

IN WATER AND FIRE

Before a steel can become a metal of superb qualities, it has to go through fire once more. This time, it is heat-treated to bring about further improvements in its structure.

That steel, heated to a red heat and quenched, becomes hard and brittle was known long ago. Homer in his "Odyssey" of the 9th or 8th century B.C. writes

"And as when armourers temper in the ford
The keen-edged pole-axe, or the shining sword,
The red-hot metal hisses in the lake..."

Masters of the past also knew that by heating and quenching the same grade of steel differently they could give it different properties. But they could not explain why this was so, because they had no idea of what is going on inside the metal on heating or cooling.

Now we can do this for them by consulting the constitution diagram in the previous chapter.

Imagine yourself in an ancient smithery. A grey-bearded smith puts a piece of steel into his forge. His helpers bend to the bellows to apply a blast. The current of air raises the coal to a white heat. Bluish smoke floats to the ceiling.

The smith keeps his eyes glued to the metal. He knows too much heat would spoil the metal—it would break down under his hammer. But he knows too little heat would make the metal unable to take a good quench. This knowledge has come to him from experience and "hunch". That is why his trade has been more of an art for centuries.

The smith does not suspect what marvelous transformations take place in the metal. When he raises his metal to 723°C, recrystallization occurs. It goes on until about 800°C, depending on how much carbon there is in the metal. The crystals that form have the power of dissolving carbon or the carbide (cementite). The metal heated to this point is a solid solution of carbon in iron, called austenite—a familiar word to us already.

If now the metal were allowed to cool slowly, the events would take place in reverse order: on recrystallization the carbide, or cementite, would be thrown out, and there would be very little carbon left in solid solution. Before that happens, however, the smith snatches the yellow-white, nearly transparent metal out of the forge and puts it on his anvil. The smith's hammer and the striker's sledge fall onto the metal in rapid succession, the smith showing where to give a blow and the striker doing as told. Before long, the narrow blade of a sword lies ready on the anvil. But there is no time to be lost on just gazing. The smith has to finish everything before the metal cools of its own accord. He picks the blade with a pair of tongs and dips it into water.

The metal is quenched so rapidly from about 800°C to below 723°C that it has no time for back recrystallization. As a result the austenitic structure is kept intact in a temperature zone where it does not belong. Yet, it cannot change to any other—such transformations cannot occur below 723°C.

The same is true of many steels. At room temperature they retain the same structure they had in the forge. Such steels are called austenitic.

Plain carbon steels do undergo recrystallization between 300° and 400°C. But the carbon is not thrown out of the crystals. Instead, a supersaturated solid solution of carbon in iron is formed, while the crystal lattice of the iron remains the same as it is at room temperature. This structure is called martensite. Steels owe their hardness to this structure.

Finally, our smith takes the quenched blade out of the water. It is no soft iron any longer. It has become many times harder and more flexible.

But there also were other methods of hardening steel in ancient times. A manuscript, found in the temple of Balgala in Asia Minor and dating back to about the same time as Odyssey, gives this advice: "Heat a dagger's blade until it glows like the sun rising over the desert, then cool it until it has the colour of royal purple by thrusting it into the body of a muscular slave. The slave's strength, going over into the dagger, will give hardness to the metal."

A bit different wording is given to the same advice in a document found in Syria. A dagger should be quenched by thrusting it repeatedly into the fleshy parts of a slave. It is stated that a slave shall be furnished by the man for whom the dagger is being made.

As the story goes, the makers of Damask steel in the early medieval Orient would give a newly made sword while it was still white-hot to a man on horseback and tell him to ride at full speed, slashing at the air.

Steelmakers have quenched the metal in running and standing water, in liquids of all conceivable compositions. Even today steels are quenched in dissolved or molten salts, oils, air, water, or molten metals. Quenching can be in two steps, rapid down to 300 or 400°C and slow below that point. It can also be intermittent or in two quenching media. Sometimes quenching is carried on to well below zero.

Today nobody among metallurgists thinks quenching media have any mysterious qualities about them, so praised by ancient and medieval blacksmiths. Simply they take what gives just the right rate of cooling for a particular grade of steel. Quenching below zero is applied to steels in which the austenite cannot fully change to martensite at room temperature.

Steels are not the only metals that can be hardened. Already the ancients knew how to harden bronzes, alloys of copper and tin. At the turn of the century the Russian metallurgist Baikov discovered that an alloy of copper and antimony could also be hardened. Later hardenability was discovered in alloys of aluminium, magnesium, lead, platinum, nickel, gold and other non-ferrous metals.

In order to harden a metal, it must be heated to, or above, a critical point, that is, a point at which certain changes take place in its structure. Then, by rapidly quenching the metal, this changed structure, ordinary at high temperatures, is made to remain intact at low temperatures. Not that the result is always the same as when hardening a steel. When rapidly quenched, an alloy of gold and copper becomes soft and ductile. When allowed to cool slowly, on the other hand, it grows hard and brittle. How to heat and cool an alloy in order to get the right result can be learned from the constitution diagrams which have now been compiled for many alloys.

MARTENSITIC ARMOUR

It often happens that a metal part should be soft in the inside and very hard on the surface. It would seem one cannot make a metal both unhardened and hardened. Yet engineers have devised methods for making such metals.

One of them works like this. A worker puts a shaft glittering with a bright, unoxidized surface after grinding into a copper coil. Then he presses a button, the machine goes humming, and in no time at all the shaft grows first cherry-red, then brightly red, and finally yellow; it is blazing.

What is it that has heated the shaft? There is no fire or white-hot parts to see around.

The trick is done by high-frequency currents. The very currents that are at work in radio receivers and transmitters. They are radiated by the copper coil put around the shaft. By a well-known physical law, they induce eddy currents in the part, which in turn generate heat. So the part is raised to a high temperature very quickly.

Then a shower of cold water is brought down on the hot part. The jets of water come out of holes in the coil which turns out to be simply a copper tube. In a moment, both the shaft and the coil are lost in a cloud of steam. In another moment, the worker removes the part from the machine. The shaft is still warm. Its surface glitters exactly as it did before hardening. The heating was so rapid that it had no time to become oxidized, while the whole operation took five or six minutes to complete.

If we cut across the shaft, we shall see that its surface has come by a hard structure, most often martensite, to a depth of several millimetres, while its core has remained soft. This is exactly what machine designers are after.

There are also other methods of surface hardening, but induction hardening, as the above method is called, is the most efficient.

At a metal-working factory you will inevitably run into heat-treating operations other than hardening. The most common among them are tempering, annealing, and normalizing.

Tempering usually comes in when a hardened metal has to be machined. Suppose a part, already finished and hardened, is to be re-worked on a lathe. The turner mounts the part, switches on the motor, and feeds in the cutting tool—only to learn that the part will not be cut. The tool slips on the hardened steel like a needle on glass. To be workable, the part must be softened, or tempered. For this, it is heated to a certain temperature and then slowly cooled, most often in the furnace. After that the tool will cut it easily.

In carbon steels, quenching gives rise to martensite, which is very unstable. It would decompose on heating to 100 to 130°C. To give the metal a more stable condition, it is tempered. As a result, some of the martensite decomposes, leaving softer and more stable structures.

Annealing can serve various purposes. One of them is to remove stresses. Here is a story about how annealing does this job.

One day the engineers at a large works making steam engines were stunned by unpleasant news: a huge flywheel ready for installation had

burst at night. The engineers were at a loss how to explain the failure: the casting had been good, the gates and risers had been removed properly, and the burnt mould sand brushed off thoroughly. The flywheel had been placed in the yard to wait for its turn to be installed in a steam engine. At night the watchman heard a crackling sound, as if someone was shooting a pistol, but no evildoers were found on the premises. In the morning the engineers found what was left of the flywheel: the spokes, as thick as a man's arm, had broken in two; the hub had dropped out of the rim and was lying like an eight-cornered star on the ground.

The failure was caused by internal stresses. Very often they destroy otherwise strong and good castings. They may weaken, distort or ruin a part after quenching. To prevent this from happening, the part is annealed: it is heated to a temperature somewhat below the critical point (where recrystallization begins), is held at that temperature, and allowed to cool slowly.

Normalizing is an annealing treatment. It is used to restore a steel part to the normal condition after hot or cold working, overheating, or to counteract the effect of a previous treatment. The part to be normalized is heated a bit above the critical point and allowed to cool in still air.

MAKING A STRONG CASE

Swallowing mile after mile, a car whizzes past you down the grey ribbon of the highway glistening after a rain. It has covered several thousand kilometres with only a few short stops for the driver to stretch his legs and for the tank to be filled up. But the engine hums smoothly as ever, and the car is fit to run on and on.

Did it ever strike you how strong and durable the parts of a car engine are? During a 1000-kilometre trek, its crankshaft makes over two and a half million revolutions, or 3600 revolutions every sixty seconds. Every minute it has to take over seven thousand blows coming from the air-petrol mixture burning in the cylinders.

There are parts in the car engine which stand up to a far rougher handling. During the same 1000-kilometre trek, the pistons make over five million strokes, reversing their travel as many times, while every valve in the engine opens and closes nearly one and a half million times. That works out to one and a half million blows of metal against metal.

Needless to say that a car runs more than a thousand kilometres during its service life. A well-looked-after car can cover 400 to 500 thousand kilometres on the same engine. In the meantime, the crankshaft will have made over a thousand million revolutions.

What sort of metal goes to make the crankshaft? How is it that its journals do not wear through and its crankpins do not break down under the numerous blows? And those are heavy blows in spite of all the tricks engineers have devised to make the engine's lot easier.

I bet you will be surprised to learn that crankshafts are made from ordinary structural steel and only sometimes from low-alloy steels. The metal is given its "thousand lives" by carburizing, a treatment which makes the metal very hard near the surface but leaves the core tough and ductile.

Carburizing consists in introducing carbon into the surface layer of steel articles. You know, of course, that when cold, iron can be left in contact with carbon for any time—none of the carbon atoms will find its way into the metal. Coal is carried in iron wagons for decades, but their metal remains unchanged. This is because at room temperature carbon is almost insoluble in iron.

An altogether different picture emerges when iron is heated to a fairly high temperature in contact with a carbon-carrying material. Its lattice changes, and the iron can now absorb as much as two parts carbon in a hundred. The thermal motion of the molecules grows ever more brisk, and diffusion—the spreading of one material through another—becomes intensive. Owing to it, the surface layer of the metal picks up much carbon.

Let us see how it is done by "pack" carburizing.

The pieces to be carburized are cleaned of scale and dirt which may block the penetration of carbon into the metal. The places where carbon absorption is not desired are given a coat of some compound or of copper in an electroplating cell.

Then carburizing pots or boxes are prepared. These are containers of cast iron, steel or a nickel-chromium alloy. Spread on their bottom is a bed of carbonaceous material called the carburizer. Most often it is a mixture of birch-tree charcoal and barium carbonate. The pieces are placed on this bed and packed from above with the same mixture. When the packing is over, the pots or boxes are covered, and all openings are luted with a non-cracking loam or clay.

Now the pots are placed in the heating furnace, brought gradually to 900-920°C, and held at that temperature for the time required to give the desired "case", as the carburized layer is called. For a case one millimetre thick, the carburizing time may be from seven to ten hours, depending on the temperature in the furnace.

Finally, the pots are removed from the furnace, and the stock is cooled in various ways.

A newer way to do the thing is by gas carburizing. Instead of pots and boxes, there is a large muffle where the workpieces are loaded. The carburizer is no longer a solid; it is a gas rich in carbon, such as methane, carbon monoxide, acetylene, and the like. The high heat in the muffle breaks down

the gas, and the freed carbon lodges as soot on the exposed surfaces. Then it penetrates into the metal by diffusion.

Gas carburizing is attractive on several counts. For one thing, it is cheaper—the stock need not be prepared so thoroughly. For another, half to one-third less time is spent and not so much fuel is burnt as in pack carburizing. Also, the working conditions are healthier. The chances are it will soon replace other methods.

Carburizing is not the only way of producing a hard case around a tough core in steels. If the steel is made to absorb carbon and nitrogen together, we have a process called cyaniding, because it uses cyanides or cyanogen. Cyaniding produces cases from 0.3 to 0.7 mm thick in a matter of ten to fifteen minutes. Where nitrogen alone is involved, the process is known as nitriding. It improves the strength and corrosion resistance of steels.

Sometimes, the surface layer of steels is impregnated with some other metal. Thus we have aluminizing, which, as its name implies, uses aluminium for the purpose and makes steels heat resistant; chromizing, which improves the hardness and corrosion resistance of the base metal; siliconizing, which makes the base metal acid resistant; boronizing, which turns steels wear resistant. Similar processes have been devised for impregnating the surface layer of steels with beryllium, vanadium, tungsten, molybdenum, manganese, cobalt and zirconium.

Steel is not the only metal that can be thus treated. Titanium, too, can be nitrided to improve its hard-wearing properties. Molybdenum articles are siliconized to make them heat resisting. Truly, the case makes out a strong case for itself.

STEEL'S RUNNER-UP

Although both steel and cast iron are made from pig iron, we shall leave out pig iron, since it has very few uses of its own. Our story will now be about cast iron.

Cast iron today does not measure up with steel in its usefulness to man. Yet it is worthy of mentioning. It is doing its best, and metallurgists are seeking to improve its quality.

What is it that sets cast iron apart from steel?

The chemist might point to the greater carbon content.

The machine designer might bitterly complain that it is weak in tension and bending and that it is unable to undergo plastic deformation.

The foundryman, on the other hand, would speak with deference of its casting qualities.

The metallurgist might name a long list of properties which cast iron has and steel has not. He might remind that grey cast iron machines well—it is soft and gives an easily breakable and small chip. Also it comes in useful where metal parts slide one upon another (this is what engineers call anti-friction properties). It damps vibrations well. It is indifferent to surface defects, and so on.

For all that, it lacks in strength. The machine designer has every reason to look upon cast iron as an inferior material of construction.

Metallurgists have a long record of efforts to tailor cast iron to particular uses. Thus there is a kind of cast iron which casts well and has uses where a cheap material with hardness and good wear resistance is required. This is white cast iron. It is so called because it breaks with a silvery-white fracture. All the carbon in it is in the form of cementite. Because of the cementite, however, the metal is hard, brittle, difficult to machine, and is not malleable at any temperature.

If a casting must be soft, easily filed, chipped or machined, use is made of grey cast iron. The name, again, comes from the colour of the fracture. When the molten metal is allowed to cool slowly, the carbon is thrown out as flakes of graphite, which is grey.

Unfortunately, the graphite is not only grey, but also weak. Intervening between the grains of the metal, the graphite flakes, which may be fairly long, pierce it, as it were, with a lot of cracks. Because of these "cracks", grey cast iron is weak in tension.

There is a way, however, of turning these long, thin flakes into widely separated spheres. When the graphite is in the form of spheres, the mass of metal is much less broken up and gains in strength. Because of the shape of the graphite, the metal is called nodular.

The change is brought about by adding a nodularizing agent. It may be either metallic cerium or metallic magnesium. Though only as little as one part magnesium in a thousand goes into cast iron, the effect is striking—the iron becomes ductile.

Then you can "inoculate" cast iron. The most common inoculants, as such additions are called, are ferro-silicon, calcium silicon, ferro-manganese silicon, and zirconium-silicon. By inoculation, high-grade cast irons are made with a remarkably uniform and fine-grained structure good for many uses.

Sometimes an iron casting must have good resistance to impact. Here, too, metallurgists have devised a trick by which that same hard and brittle white iron is turned into what is called malleable iron. It is not to say that

malleable iron can actually be forged. What is meant is that articles made from it have the properties of forged metal.

This is how white iron becomes malleable. A white-iron casting is packed with sand in a steel box, called a "sagger". The box is placed in an annealing furnace, and gradually, during twenty to twenty-five hours, the furnace is raised to 950-1000°C. The casting is held that hot for another twelve to fifteen hours. Then a few more hours are spent to cool the stock to 700°C at which it is again held for a day or longer. Thus, it takes a total of seventy to eighty hours to turn white into malleable iron. Sometimes the process will take 140 to 170 hours. Another trend, though, is to squeeze it inside thirty hours or even less.

The annealing breaks down the cementite of the white iron into nodules of temper carbon. They are only a bit larger than the graphite spheres in nodular iron, and the tensile strength of malleable iron is only a little lower than that of its nodular counterpart.

Finally there are alloy-type cast irons. They come in where strength and resistance to wear are required. Among the alloying additions used are silicon, manganese, chromium, copper, molybdenum and nickel.

These additions differ in their effect on cast iron. Silicon, for example, is an efficient graphitizer and "softener". The more silicon there is in a cast iron, the easier it is for graphite to form on cooling. Manganese, in contrast, is a "hardener"—it promotes cementite formation as in white iron.

Any cast iron also carries the impurities sulphur and phosphorus. Sulphur is similar in action to manganese. On top of this, it makes cast iron less fluid when molten, and the metal fills moulds rather poorly. It is usual to keep the sulphur down to one part in a thousand.

Phosphorus, on the other hand, has no effect on graphitization, but it makes cast iron rather brittle. Yet, there is an application in which phosphorus is welcome.

All of the best museums the world over feature exquisite sculptures glittering with black metallic lustre. Among them you can see the preposterous Don Quixot, horses sprawling above the steppe three abreast, and an old woman bending over a distaff. In company with them are beautiful vases with blades of grass and leaves stuck to their walls, so much real, showing every fibre. And next to them are the laces of grilles and the austere lines of chandeliers. All those things have been cast in iron at the Kasli Foundry, the Urals.

It was founded in 1747, and since then, for more than two centuries, its masters have been making amazing things out of crude, unmanageable iron. Very important in their know-how is the use of high-phosphorus iron.

Say the Kasli masters: "Phosphorus, it is true, impairs the mechanical properties of cast iron and makes it brittle. But our products are not hammers or cold chisels. Few blows fall to them. But phosphorus makes the metal very fluid when molten and slow-freezing, so it fills moulds all right. In our trade, this is much more important than resistance to blows."

There is no denying, cast iron is an ideal material for founding. It has a rare and remarkable property—it expands on cooling. Only water also does so. This is why ice floats on water, and solid cast iron on the molten metal. On cooling, cast iron becomes pasty, and graphite is thrown out of it. Since it is of low density, graphite takes up much space. As a result, the casting expands, and the metal fills all the corners and nooks in the mould.

Today cast-iron products are sometimes as good as those made of steel. This is true of pipes which can stand up to high pressures, piston rings which have good anti-friction properties, and even crankshafts, although it may surprise you. The only thing that cannot be done with cast iron is rolling. On the whole, however, cast iron still remains steel's runner-up. But as we can now see, it would be pointless to try and make it superior to steel—cast iron is a good helper to steel as it is.

HARDENED BY WORK

There is one more way of improving the hardness and tensile strength of metal, one which does not call for any alloying additions. This is cold working. It produces what is called strain or work hardness.

When a metal is deformed permanently, say, pulled beyond its yield point, its resistance to distortion increases—we saw this happen to a steel specimen in one of the previous chapters. It looks as if the metal, after it has lost some ground, regains its strength and puts up a stiffer resistance to deformation.

For the same reason when a piece of steel is mechanically worked, or strained, permanently at room temperature, a hard surface structure is developed.

In some cases this is done by blasting the workpiece with a hail of steel balls. Shot by compressed air, they strike at the surface of the metal, breaking down the crystals and making them harder.

In other cases the same effect is obtained by drawing the workpiece between very hard rolls. And again, the crystals are broken down to give added hardness to the metal.

Either of the methods produces a cold-worked layer not more than 0.2 mm thick. Yet, the metal gains much in strength, including resistance to fatigue.

The designer has completed the drawing of a machine. He has listed the materials to be used for each part and specified the type of treatment they should be given to improve their strength. Here and there on the drawing you can see the inscriptions: "To be forged before machining", "To be carburized", "To be given such and such hardness."

But there is one more thing in the drawing you may well pass unnoticed. It is where the designer has done his bit to add strength to the machine.

Look at the stepped shaft in the drawing and note the fillets made where there is a sharp change in diameter. No, beauty has nothing to do with them. They are a way of improving the strength of the part. Without fillets, stresses would concentrate at sudden changes in diameter, and the shaft would be bent or broken there.

Make a simple experiment. Put two books on edge—they will be the sides of a gorge to be spanned by a bridge. The bridge will be a sheet of paper. Place the paper over the edges of the books. It will sag under its own weight, to say nothing of any added load.

Not that the paper lacks in strength. Simply you have not utilized it properly. Fold the paper lengthwise on both sides into a sort of trough and place it on the books with the folded edges down. Now the "bridge" will be much stiffer. It will easily bear the load of several pencils, a rule and even an ink-stand. And this is no limit to the strength of the sheet of paper.

The machine designer knows how to enhance the strength of a part by choosing the best form or shape for it. He knows that a tube of the same material, weight and length as a solid bar will stand up to a greater bending or twisting stress. Through a slight change in part disposition he can turn bending stresses into tensile or compressive ones. Without so much as a look at the drawing, he will tell you where a channel is better to use than an I-beam, sheet metal better than a solid slab, or rolled shapes better than formed sections. Looking at the way he tackles all sorts of problems that go with any structure, you cannot help admiring the ingenuity and elegance that are embodied in them.

It must be admitted frankly: this does not come just to any designer easily, always or overnight. Look at the designer when he stands before his drawing board. He is pecking absent-mindedly with a pencil at the edge of the board and humming tunelessly to himself. But in his brain a thrilling search is going on for the best solution, conflicting alternatives are being confronted in a passionate way, the desired and the feasible refusing to reconcile themselves dramatically. As much inspiration and feeling and, of course, much less knowledge are required to compose verses. Good machine designers are as few and far between as good poets.

Speaking of the strength of metals, we cannot forget their durability.

Everything in the world has a beginning and an end. All things around us—people, planets and galaxies—come and go. Only matter is eternal, always changing and developing, never retracing a path it has taken once.

Man is working—and successfully, for that matter—to extend his life span. And Death, that bony figure with a sharp scythe, has to retreat. During the past forty years the expectation of life in the Soviet Union has nearly doubled. In the future people at 165 will be as common as they are at 70 now. It may so happen that old age will not come till 360. Physicians and biologists working on the problem of longevity do not see why the life span of man cannot be extended practically indefinitely.

Well, what about metals? What is their span of life?

It depends on the way a metal lives—quietly or violently. Academician Bardin has once likened metals to two animals, a fiery horse galloping over hills and dales, and a slow tortoise never hurrying anywhere. Tortoises are said to live to the age of 300. Horses seldom live to the age of thirty. The same is true of metals. A kitchen knife can last as long as a tortoise, while an engine hardly has any chance of reaching the age of a horse— its life is too violent for that. It has to bear the brunt of exploding petrol, the whirls of hot gases, thermal and shock waves. That the mass-produced metals of machine-tools, engines and mechanisms have today a life span of thirty-five years is a major success of metallurgists, Bardin says.

Yet the life of metals can be extended many times. Take Damask scimitars, for example, which are as good today as they were at the time of the crusaders. Or stainless steels which are even more durable than Damask steel. But those are special steels, you might say, and what about the ordinary grades that make up the bulk of the metal produced commercially?

Metals decay for various causes. Some yield to fatigue, others fail because of the wear on rubbing surfaces. A good deal of metal is destroyed by corrosion.

Corrosion is a voracious thing. If man did not protect metals, it would eat up all that he has produced in a matter of three years at the most. The piers of bridges, the hulls of ocean-going liners, and the roofs of factories would all collapse into heaps of loose rust. The metals would be turned back to their ore.

But man does protect metals. And he does this in a multitude of ways. Still, for all his efforts, corrosion does take a high toll.

Between 1890 and 1923 man produced 1,766 million tons of iron and steel. Out of this amount corrosion took back 718 million, or more than a third, over the same time. At present, its loot is put at not less than on tenth of all metal produced.

Every one has seen the Red Death which kills iron and steel. It turns up as scabs which look like clots of blood mixed with dirt on once polished surfaces and make them spongy and pitted. On copper, corrosion leaves a venomously looking green film. It spares not a single metal, including gold and platinum.

It is hard to imagine all harm done by corrosion. Because of it, water taps sometimes become dry—corrosion has eaten up the water pipes. Because of it, chemical plants have often to be shut down—corrosion has destroyed some vital parts. Because of it, feed water for boilers has to be de-aerated. Because of it, huge sums of money are spent to paint, blue or lubricate metal parts. The combat against corrosion is a never ceasing effort. And today man has something to show for it.

Corrosion occurs in two general forms. The first, known as chemical corrosion, is the direct combination of elements with metals to form compounds. It takes place in dry gases and liquids which do not conduct electric current.

Perhaps you remember how, back at school, your chemistry teacher took a piece of sodium, that remarkable metal, out of a kerosene-filled jar and cut it with a penknife. The fresh cut showed a mirror surface, but in a minute or two it would be covered by a grey, dull film of oxide. That was chemical corrosion.

Another example is the scaling of iron at high temperature. The oxygen of the air combines with the iron to form iron oxide.

The second form, electrochemical corrosion, is more complex. To grasp the way it works, recall the simplest electric cell, a copper and a zinc plate dipped in an electrolyte. When the two plates are connected by a wire, an electric current begins to
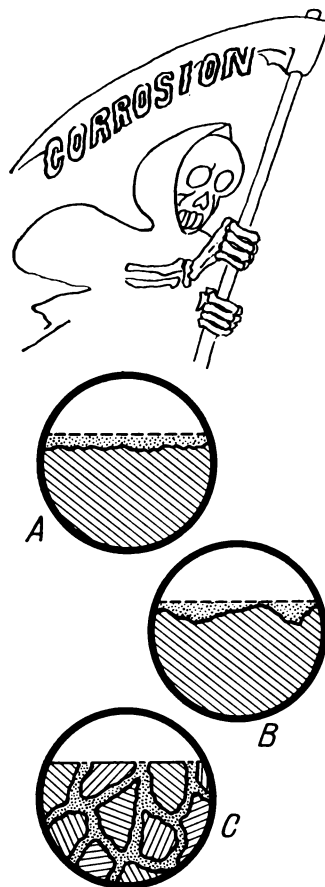
The ways of the Red Death

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flow through the electrolyte and wire, and the zinc plate turns to zinc oxide.

A sort of electric cells always exist in metals. Any metal is non-uniform in composition (except very pure metals). There always are foreign inclusions, and the grains of the metal also differ in nature. In steel, for example, cementite is different from pure iron, or ferrite. So, in an electrolyte, an electric cell is set up and a current flows between different parts of the same metal, much as between a copper and a zinc plate. As to the electrolyte, it is always at hand: seawater, river water, atmospheric moisture. Seawater is a very strong electrolyte. River water also contains dissolved salts. Atmospheric moisture picks up and dissolves the oxides of carbon, sulphur and other elements present in the air. These oxides are particularly abundant in the urban atmosphere. This is why an iron roof, if it is poorly painted, rusts quickly in towns.

Corrosion, both chemical and electrochemical, can show up in several ways. In some cases it is a uniform attack or general wastage, as at A in the picture. In others it takes the form of pitting, as at B. But corrosion is at its worst when it breaks through into the metal, as at C. The corrosive attack then penetrates along grain boundaries —where the material is weakest and non-uniform. From the outside the metal looks strong and healthy, but inside it has already succumbed to corrosion. It will break down under a blow or in tension long before its maximum strength is reached.

We have said all metals are prone to corrosion. But what about chromium, gold and aluminium? Hasn't it been said they show a remarkable resistance to oxidation?

Well, they oxidize too. Chromium does so as soon as it comes in contact with air, and a thin film of oxide, transparent but strong, is formed on its surface. It is this film that protects the underlying metal from further attack. A similar film, though less transparent, covers aluminium. It plays down the blue metallic lustre of unoxidized aluminium and gives it a dull surface. But again it stops any further attack on the underlying metal.

This property of some metals to form protective oxide films on the surface has come to be used as a defence for metals which cannot resist corrosion by themselves. Most often, protected metals are steels, and the protecting medium either nickel or chromium. You have certainly seen nickel- or chromium-plated parts, such as car mouldings, measuring tools or household things.

A very interesting way is sacrificial protection against corrosion. To understand its action, we shall go back to our electric cell made up of a

copper plate as the cathode and a zinc plate as the anode. Of the two plates, the anode is wasted in operation. If, instead of copper, we use magnesium, the zinc plate will remain intact, and the magnesium will go into solution instead. It looks as if the magnesium "sacrifices" itself to save the zinc, which has now become the cathode.

If we arrange metals according to their tendency to go into solution in a cell, we shall have the so-called electrochemical series: potassium, sodium, barium, calcium, magnesium, aluminium, manganese, zinc, chromium, iron, cadmium, cobalt, nickel, lead, tin, bismuth, antimony, copper, mercury, silver, platinum, and gold.

Whichever pair of metals is taken from this series as the electrodes of a cell, the one above the other will always be the anode, i.e., it will be wasted. From this the idea has come to protect ferrous metal structures by means of "sacrificial" anodes. They are sacrifices indeed! The ancient Cretans offered seven youths and seven maidens from Athens as a sacrifice to the Minotaur, a bull-like monster confined in a labyrinth, lest he should do a bigger harm. And today we do much as they did by sacrificing pieces of zinc or manganese, to save a steel gas pipe line, the supports of a structure, or the hull of an ocean liner.

This is how it's done in practice. Sacrificial anodes made of a magnesium- or zinc-base alloy are buried some distance from the pipeline to be protected. Spaced about fifty metres apart, these galvanic anodes are wasted over a period of several years. Then they can be renewed, while the pipeline suffers no damage.

Another effective way is cathodic protection by application of an electrical current from some external source, such as a battery, generator, or rectifier. The plus side of the source is connected to the structure to be protected, and the minus side is earthed through an old rail or tube buried in the ground. The flow of current is such that corrosion cannot attack the structure.

Now that we've learned the chemistry of corrosion, we are able to understand how, say, the zinc or nickel coating protects the underlying metal.

Zinc stands ahead of iron in the electrochemical series. Therefore, when iron is galvanized (this term means zinc-plated) and a small break in the zinc coating occurs, a simple galvanic cell results in the presence of atmospheric water. But only the zinc passes into solution, while the iron—at least those parts close up to the zinc coating—remains uncorroded. The zinc will "sacrifice" itself to the last grain (we may say, to the last drop of blood) protecting the iron.

Things are different with the nickel coating. For nickel is below iron in the electrochemical series. Should a break occur in the nickel plating,

corrosion will attack the iron, leaving red rust behind. Indeed, rusting can spread under the nickel, hidden by it from man's watchful eyes.

Sometimes, however, corrosion cannot be fought back by any of these methods—metal coatings, painting or sacrificial anodes. But even then metals are not left unprotected. This time inhibitors come to their rescue.

Inhibitors are substances which are added to the environment in small concentrations to form protective films which retard corrosion. Some inhibitors are added to sulphuric or hydrochloric acid so that it can be carried in iron tanks. At the user's, the inhibitor is extracted from the acid, and it again becomes aggressive.

Very often inhibitors are added to paints and varnishes. Then, even if there is a break in the paintwork, the moisture reaching the metal through the coat of paint will dissolve the inhibitor, and the solution thus forming will prevent corrosion.

The efficiency of corrosion inhibitors was once proved experimentally. A batch of sewing needles greased with petroleum jelly was wrapped in paraffin-treated paper. That is how sewing needles are usually kept in storage. Another batch was wrapped in paper treated with a solution of inhibitor. After several months the wraps were removed. The needles from the first batch showed fairly heavy signs of corrosion. Those from the other batch had not a single trace of rusting.

Unfortunately, inhibitors are very selective in their action. Some can protect only ferrous metals, others only non-ferrous metals. It is not unlikely that with time universal inhibitors will come along.

A good deal of success in corrosion control also depends on the designer of the structure. A racing yacht was once built. That was a superb craft with a narrow, elegant hull, a copper-nickel plating and a steel keel—the right thing for fast sailing. When the yacht had been launched, her owner was lost in admiration of his possession. But the yacht broke apart well before the race. The steel keel and the copper-nickel plating made up an excellent galvanic cell, and the keel was eaten away by corrosion. Who was to blame? The designer, of course.

This is why designers take every precaution to use the right metal in the right way in the right place. They will never allow direct contact between aluminium alloys and copper, brass or stainless steel. If such combinations cannot be avoided, inert spacers are placed between the mating surfaces. The designer also sees to it that sacrificial anodes are provided where necessary and protective coatings are applied where critical parts are exposed to aggressive liquids.

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IN THE HANDS
OF THE GREAT MASTER
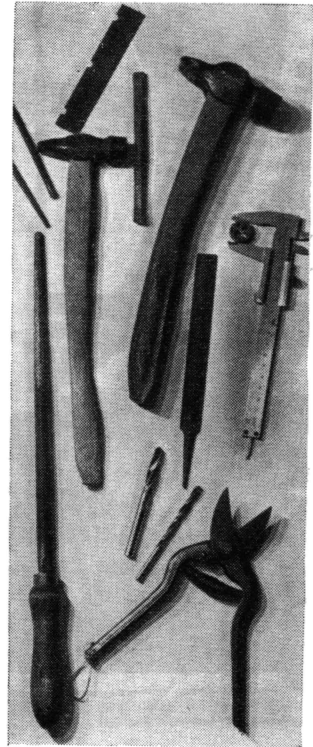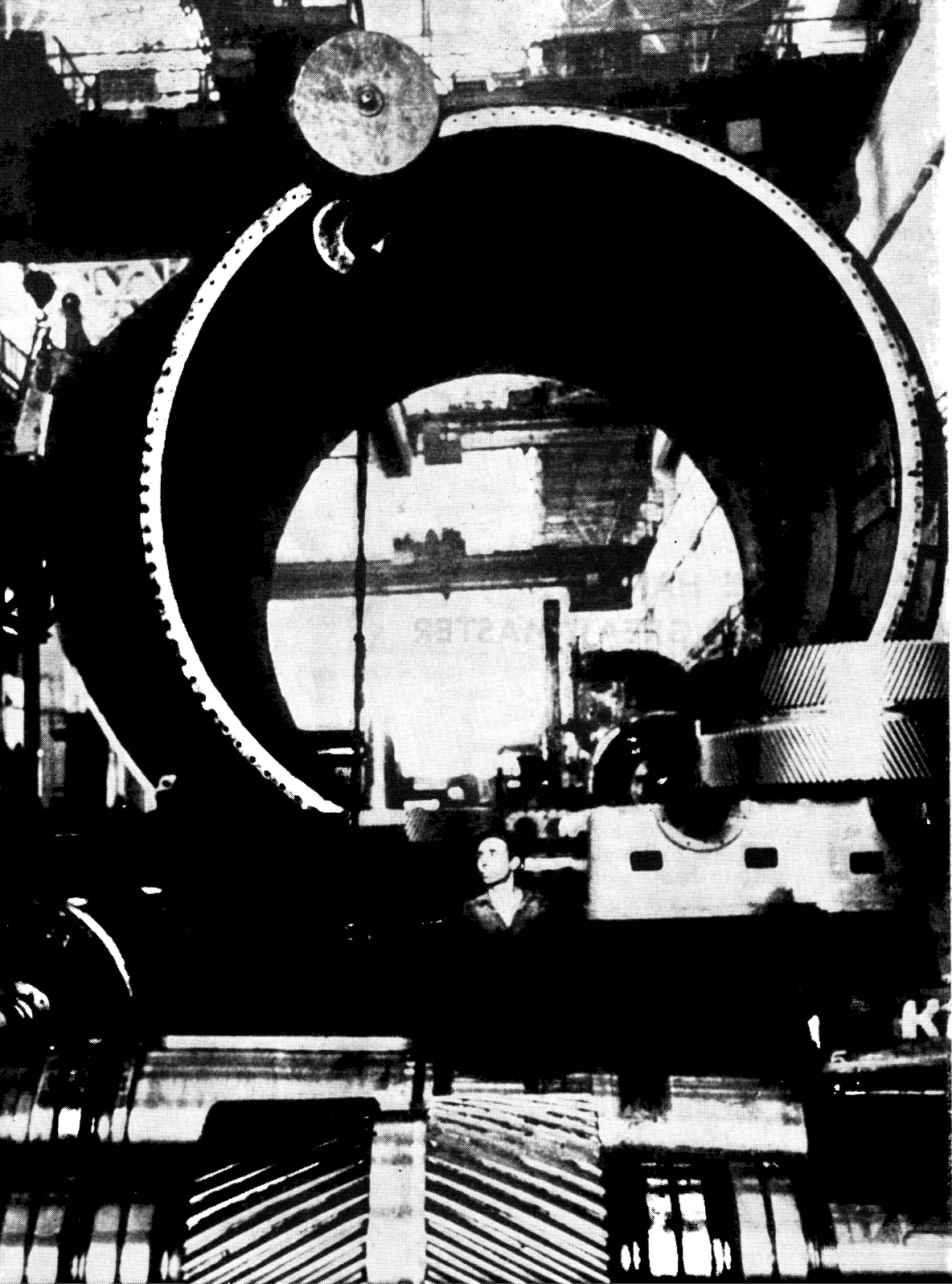
What it is today, iron owes to man, that great master. Man has built artificial volcanoes, blast furnaces, where the fiery lava of pig iron is melted from reddish-grey or black ores.

Man has found hundreds of additions which improve weak iron, giving it properties non-existent in nature.

Man has invented heat treatments and surface impregnation through which the very structure of iron can be changed at will, turning it, soft and pliable, into the diamond-hard blade of a sword or the strong and tough plates of ship armour.

Man has boldly set out against corrosion to extend the service life of iron many times.

What would iron be, but for man? Just rusty lumps uselessly eroding in mountains.

What has iron become in man's hands? The foundation of a second nature, the skeleton of the pyramid we call civilization. Today the top of the pyramid has reached the Moon; tomorrow it will touch Venus and Mars; before long it will extend as far as other worlds.

Man has won many victories over nature with iron's assistance. But before them he had to win his victory over iron itself.

To get iron from ore, to make it strong is only half the job done. Now it must be given the shape necessary in a particular structure or machine.

Man has learned this too. He has devised machines which squeeze and form steel ingots as easily as a child works clay. Other machines cut the hardest steels with tools also made of steel. When they fail to do the job, man uses diamond, electrical sparks, or ultrasound. Still other machines form shapes straight from molten metal.

That is why man's victory over iron is probably most vital.

THE SHAPING OF IRON BY CASTING

Casting is one of the most ancient ways of forming metals. Over sixty centuries ago bronze was cast into stone moulds. Since then hardly a single thing has remained unchanged in the foundry, but the main principle has — the molten metal is poured into a mould which has the shape of the desired product, where it solidifies.

In the meantime, man has devised a multitude of other ways of forming metals: huge forges, presses, rolling mills, and basically different processes. Yet, casting firmly holds ground. Castings account for as much as four-fifths of its weight in a metal-cutting machine, about a half in a tractor or a large hydraulic turbine, and close on a quarter in an ordinary goods wagon.

The foundry of today can make castings very intricate in shape, which are beyond the capabilities of turning, milling, forging or pressing. You can hardly make an ordinary by-pass valve, a barrel-shaped piece with three openings and a wall curved on the inside, by pressing or machining. Even if you did try to, it would cost its weight in gold after all those operations! The only reasonable way to make valves, which are used by the thousand, is casting.

Castings may be very small, weighing a few grams, and very big, weighing tens and even hundreds of tons. Castings can be custom-made and mass-produced. They can be cast in iron, steel, or non-ferrous metals, except the most refractory ones. They can be cast in alloys which cannot be machined, such as white iron and many aluminium-base alloys.

Of course, there is something in which casting is inferior to other ways of forming metals. A cast crankshaft is not so strong as one turned from a forging. Some machine parts, when welded, take less metal to make than when cast. But, losing ground to welding in some areas, casting is taking over in others — and quite unexpectedly. Casting is beginning to be used

where it has never been employed before—to make turbine blades and shafting, milling and cutting tools, for example.

The first step in casting is to melt the metal. Iron is melted in the cupola, that smaller counterpart of the blast furnace. It is a metal cylinder some ten metres high and up to three metres in diameter, lined with firebrick.

The cupola is charged with coke, flux, iron pigs and steel or iron scrap. The air blast is put on through a system of tuyeres. As in other types of furnaces, it does much good to enrich the blast with oxygen.

The molten metal and slag collect in the hearth at the bottom of the cupola. Some cupolas have forehearths for this purpose. Depending on their size, cupolas can melt from one to twenty tons of iron an hour.

Steel for casting is melted in small-size open-hearth or electric furnaces. For non-ferrous metals, use is made of various electric furnaces.

Now imagine the hearth of your cupola is full of molten metal. It's time to tap it and pour it into a mould. And what is a mould?

In simple words, a mould is an imprint of the casting you're going to make, in a suitable material. To make it, you need a pattern of the casting. You can't use a finished article for the purpose. The reasons for this are as follows. To begin with, the pattern is made a bit bigger than the casting so as to take care of the shrinkage the molten metal undergoes as it solidifies, and of the contraction that takes place when the casting cools to room temperature. Next, the pattern is not always the same shape as the casting. Usually where the casting is to have holes or hollows, the pattern has lugs, generally painted black. You'll learn why this is so a bit later.

Small articles are usually cast in moulding boxes or flasks split in two. They may be made either of wood or of metal. The bottom half, or the drag, is laid with its joint side down, the pattern is placed in it, and moulding sand is rammed around the pattern. Then the drag is turned over and the upper half, called the cope, is put on, and more sand is shoveled in and tamped about the pattern. The sand in the cope is pierced with at least two holes reaching as far as the pattern, one for pouring molten metal and the other for escape of air and gases. Now the flask is again taken apart, the pattern removed, and a core (or cores) inserted, if holes or hollows are to be produced in the casting. Made of a mixture of suitable materials, the core is supported by the black-painted lugs (now you know why these lugs are provided). Finally, the cope is placed on top of the drag, and the mould is ready for pouring.

What you've just read is but a very sketchy outline of so-called sand casting. The actual practice is far more complicated. Take, for example, the preparation of moulding sand, which is a veritable art in itself. There

is facing sand which comes in direct contact with the casting, heap sand used to fill in back of the facing, and filler sand, which is a coarse sand or cinder to give good venting when needed. A good facing sand must be strong enough to resist the onrush of molten metal. It must also be refractory and carry no materials that would "burn" fast to the casting.

Mixing formulas and practices vary in different foundries. The basis of the mix is the sand which has already been used in casting. To it are added fresh materials, such as clay, sand, coal breeze, sawdust, and certain binders. Still more sophisticated mixtures are used for cores. A core mix usually carries oils, water glass, cement, or sulphite lye. Sometimes cores are baked at up to 250°C, and reinforced with steel rods or nails.

Add to this that many thousand tons of such materials have to be prepared—one ton of castings takes an average of six cubic metres of moulding sand and about half a cubic metre of core sand, while their volume is forty times that of the casting—and you'll realize why whole departments are busy preparing sand at large foundries.

Finally, the stream of molten metal, lighting up the foundry like a sunray, vanishes in the gate of the mould. As soon as the metal has become solid, the mould may be broken up—it has served its purpose, and the casting removed and cleaned of clinging sand and cores. That is a critical job taking, as it does, a good deal of manual labour.

This is why every effort is made to mechanize the finishing operations. Castings are shaken out of their moulds on jolting or vibrating shake-out grids. The jolting or vibrating grid makes the sand break up and fall through, leaving the casting on the grid. Cores are knocked out by jets of water in suitable chambers. Forced by a pressure of up to one hundred atmospheres, such jets act as a crow-bar. If you strike at it with a wooden stick, the stick will break. Cleaning is done in tumbling barrels if castings are small, or in sand and shot blasters if articles are large. In blasters, clinging scale and sand are removed by a current of air and sand or shot. The same principle is used in hydroblasters with the added advantage of no dust produced.

Then there are machines to prepare moulding sand and to make moulds. Moulding machines can be very big. The one in operation at the Urals Engineering Works handles moulds up to forty tons in weight. The same works is using a vibratory shake-out grid which can easily knock out moulds made on the forty-ton moulding machine. With them labour productivity has increased twenty times.

Yet, it would be very much better to do away with all these auxiliary operations—sand making, shaking out, and blasting. So that you can see this for yourself, I'll take you on a visit to the world's first automatic factory making pistons for motor-car engines in Moscow.

At that factory the melting furnace discharges into a casting machine. Every few seconds the machine pours an exact quantity of molten metal into a chill mould which looks like two cupped palms held together. Without spilling a drop of metal, the mould moves toward a conveyor. By the time it gets there, the casting grows solid, the mould halves separate, and a mechanical hand catches up the casting to place it on the conveyor.

The empty "palms" move back to the casting machine, a blower cools them, and a special device lubricates them so as to enhance their durability. Then they close again to receive another portion of molten metal.

That is chill, or permanent-mould, casting. It is equally good for non-ferrous metals, steel and iron.

The advantages of chill casting are many. For one thing, castings can be turned out at a high rate. For another, the process can be easily mechanized and automated, as we've just seen at the engine-piston factory. Also the quality of castings is greatly improved. A major drawback of the process is that it can be used only where a large number of castings of the same form should be made. It would be too costly to make a chill mould where only one casting or two are required.

Unfortunately, chill casting is no good where articles have very thin walls—the metal solidifies before it has filled all of the mould. A way out is offered by die casting.

In die casting the mould is placed in communication by a gating system with a pressure chamber in which a piston is made to move. As the piston goes up, the metal fills the chamber. Now the piston goes down, bringing heavy pressure to bear upon the metal. The metal is squeezed between the walls of the chill mould until it fills all of its space. That's very easy for it to do—the pressure is thousands of atmospheres. The air from the mould escapes through clearances a fraction of one millimetre wide—too narrow for the metal to run out even under a pressure like that.

Die casting is remarkable for dimensional accuracy and surface finish. In most cases you may well do without machining. Unfortunately, foundry-men have not yet learned how to die-cast ferrous metals. They lack materials for dies and moulds strong enough for the heat and pressure involved. Indeed, even in the case of non-ferrous metals it is confined to what would be small parts in sand casting. But the process is new and has a great future before it.

Foundry-men noticed long ago that pressure improved the cast metal. With time they came to use what we know as centrifugal casting today. In this process the molten metal is poured through a movable sprue which

moves from end to end of the mould rotating about its longitudinal axis. Rotation of the mould produces a centrifugal force which drives the metal toward the outer rim. The pressure that comes from this force increases the density of the casting, drives off entrapped gases and expels inclusions to the inner surface. By this process you can make high-quality cast-iron pipes, piston rings, bearing liners, and gear blanks.

Small castings can be advantageously made by investment casting. In this process you first make a master pattern, preferably in steel, brass or bronze, and from this you prepare dies, usually in soft metal. Work patterns are then made by injecting either wax or some plastic material into the dies. With such dies, you can make as many work patterns as necessary. A wax pattern is then joined to a wax gate, and both are coated with a slurry of fine refractory powder. After drying, the pattern is placed in a moulding box, and refractory material is packed around it. After the mould has been dried and cured, the wax pattern is melted out by a fairly high temperature to be sure no wax has been left in it. Finally, the molten metal is poured into the mould.

By this process you can make castings as precise as by die casting. Hence comes another name for it—precision casting. A descendant of the old "lost-wax" process, it is coming into ever wider use.

Investment casting has a close relative—shell casting. It is so called because the moulds are thin shells. To make them, a metal pattern is heated to 200-250°C, and a dry powdered sand-resin mixture is brought in contact with it. This is done in such a manner that the resin (usually, bakelite) rapidly forms a shell of the requisite thickness on the pattern. While still on the pattern, the shell is cured, or hardened, by heating in an electric oven at about 300-325°C for one minute. Two such shells, removed from the pattern, are used as a mould for casting. They are joined together, placed in a box and packed around with moulding sand. Because of high production rate and the readiness with which it can be mechanized, shell casting holds out great promise.

Founding uses not only high pressure, but also high vacuum. In vacuum casting a hollow copper mould is dipped in molten metal. In the space between the walls water is made to circulate, and air is evacuated from inside the mould. Because of the vacuum, the molten metal is drawn into the mould. On coming in contact with the cool walls, the metal grows solid. If air is now let into the mould, the metal will run out, leaving behind a thin crust on the mould. On cooling, we shall get an

excellent casting—vacuum goes a long way towards improving the quality of the cast metal. For all the advantages, however, this process is so far limited to non-ferrous metals and mass-produced articles.

So the ancient art of founding has today become very sophisticated, using, as it does, high pressure and high vacuum, centrifugal force and synthetic resins. Yet, sand casting remains the most common.

Meanwhile it suffers from many drawbacks. We've already seen that. The preparation of moulding sand and the cleaning of castings, for example. But how else can one possibly make a cast-iron part for a hydraulic turbine? Neither vacuum casting nor die casting will do. The only way out is to put up with the inconveniences of sand moulds. For the time being, of course, until someone comes out with another casting process—as versatile, but more convenient, fast, and clean. And there can be no doubt that someone will do that.

CONTINUOUS CASTING UPHILL

New methods for forming metals do not come just every day. Cutting, casting and forging have come down to us from ancient times. The first authentic drawing of a rolling mill for tin has been found in Leonardo da Vinci's papers. It was the more so thrilling, therefore, for me to meet the inventor of a fundamentally new casting process in the summer of 1959. That happened at the USSR Industrial and Economical Exhibition in Moscow, and the invention was so unorthodox that I'm still at a loss how to class it, casting or rolling.

Its inventor, Professor Alexander Stepanov, D.Sc. (Physics and Mathematics), stood at a stand in the Academy of Sciences' pavilion, talking quietly about his discovery. This is how it works.

You dip the dummy bar, a length of pipe, into a cell filled with molten aluminium. Just as the end of the dummy comes in contact with the molten metal, you lift it and pull an exact copy of the pipe out of the melt owing to molecular cohesion. You pull the pipe at the rate of ten to twenty metres an hour, fully finished, with smooth walls and accurate dimensions.
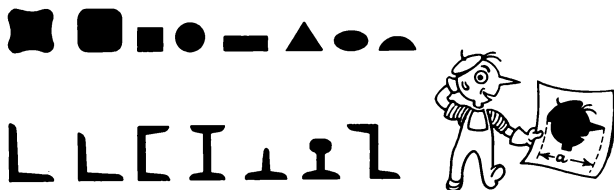
Shapes are many — how about mine?

"Piping is not the only product you can make this way," said the professor. "This is a gear blank", he held out a bar with ribs running the whole length of it. "What's left to do is to cut off gears. In effect, any shape and section can be made, even such as cannot be produced by any other process: foil a fraction of a millimetre thick, heavy-gauge beams, thick-walled pipes, and standard structural shapes. They can all be made without intermediate steps and even without machining afterwards."

It may be added that not only metals but any materials which can be melted can be worked by the new process.

That is how new things come into being. Millions have seen honey being pulled by a spoon out of a jar. But nobody, before Stepanov, had thought of using the thing as a metal-forming process. We can only guess how many things, simple and known to anyone, are waiting to be put in man's service.

You can't expect just everyone to do this. For any discovery looks simple only after it has been made. Then people begin to think they could have done it too.

BY SHEER FORCE

In one of the previous chapters we learned that sometimes man uses sheer force to get what he wants from metals. That is mechanical working which covers rolling, forging, pressing and the like. We also learned about the blooming mill through which three-fourths of all the steel and the greater part of non-ferrous metals and alloys pass.

Yes, the greater part, but not all of them. For some metals do not yield to rolling, pressing, forging or any other type of working. You can see this for yourself by trying to forge a piece of cast iron. Malleability is said to be a leading feature of metals. "Bodies that can be forged", Lomonosov used to define them. But your piece of cast iron will not. Instead, it will break under your hammer.

Nor is cast iron more workable when hot. At some works experiments are under way to roll cast iron heated to 1100-1200°C. But it is long before the process will be used commercially. So cast iron, in company with a long line of other metals and alloys, belongs to materials that cannot be worked mechanically.

Fortunately enough, most of the metals used in engineering can be worked mechanically, either hot or cold. We've said "fortunately" because mechanical working offers quite a number of advantages over machining.

When worked mechanically, a metal piece changes in shape, but not in volume. In rolling, all of the metal is turned into, say, a rail. In wire-drawing, all of the metal is made into a wire. Mechanical working leaves

practically no wastes. The two to four per cent of metal that is lost is only in the form of scale forming on reheating or as chips when ingots or billets are fettled.

In machining, on the other hand, any change in shape entails removal of some stock. When, by way of experiment, a motor works in Moscow tried to make cap nuts weighing 187 grams by machining and by stamping, the waste was 379 grams and as little as 14 grams, respectively.

One nut is nothing. But when nuts are made by the thousand, the waste heaps up into a whole fortune. Even custom-made parts are costly when manufactured by machining. Until quite recently, a turbine works used to make rotors weighing 2.8 tons from castings 9.7 tons in weight. That worked out to 6.9 tons of chips for every rotor, and there are tons of them in a big turbine.

Compared with the wastefulness of machining, the reasonable economy of many types of mechanical working is a major advantage. But not the only one.

The point is that mechanical working changes the very microstructure of the metal because of plastic deformation. When done properly, mechanical treatment will improve its physical and mechanical properties. Rolling, for example, builds up weak areas and makes the metal denser and stronger. Forging turns the fibres in a favourable direction. Cold working adds hardness and tensile strength to the surface of the metal through strain hardening.

This is not so with machining. The cutting tool removes only a surface layer of stock without changing the microstructure of the metal. In fact, as often as not it produces weak areas by severing the fibres.

The production rate is likewise greater with mechanical treatments than with machining. You cannot even imagine a planing machine capable of making steel rails from billets as fast as they come out of a rolling mill. And a sheet mill turns out thirty to thirty-five metres of sheet every second. That works out to one hundred kilometres of sheet an hour—the speed of a good car.

Mechanical working is employed to make a great multitude of products. Rolling provides an excellent example. There are rail mills, structural shape mills, wire mills, sheet and plate mills, pipe mills, tyre mills, wheel mills, and so on. They produce square, round, semicircular, rectangular and oval bars, angles, channels, I- and H-beams, tees and zees, rails and pipes, plates of armour and ribbons of foil.

Rolling can be done hot and cold. The hot rolling of steels begins at 1250-1000°C, depending on the grade, type and class of a steel, and is completed at 900-800°C.

But why to reheat the steel? If not hardened, it is ductile enough even when cold, you might object. This is done in order to improve the ductility and reduce the strength of the workpiece. Reheating a steel having an ultimate tensile strength of 80 kilograms per square millimetre brings it down

to 7.5. High ductility means low resistance to deformation—an ideal condition for rolling!

Reheating for rolling can be done in either fuel-fired or electric furnaces. The furnaces may be of the box or the continuous type. In a box furnace, the temperature is the same throughout the furnace space. In a continuous furnace, the temperature rises gradually and continually as the workpiece travels through it.

Steel is usually reheated in fuel-fired furnaces, and non-ferrous metals in electric furnaces. In electric furnaces it is much easier to keep the temperature within the narrow limits essential to non-ferrous metals.

A more recent—and a much better—method is induction heating. I've seen induction furnaces in the forge department of a motor works in Moscow. You'd hardly recognize in it the descendant of the ancient smithy! There were neither smoky hearths with exhaust hoods above them, nor heaps of coke and cinder in a corner, nor pieces of burnt iron on the floor. The walls were brightly painted, and the floor was tiled. The windows, large and broad, were opened to let in the spring breeze. That it was a forge shop you would only guess from the sight of air-operated hammers and hydraulic presses.

But that was a forge shop all the same. Blanks were put into devices which looked like round tables. Inside a minute or two they were raised to the requisite heat. An operator sporting a white smock would take out a white-hot blank, place it under the die of a press, and remove a finished part in a few seconds.

All rolling mills are built and work very much like the blooming mill you've already read about. Standing apart from them is the mill for rolling seamless tubing. In the Mannesmann type, a heated billet is pushed between fancy-shaped rolls which are set at an angle to each other and revolve in the same direction. The billet rotates in the opposite direction and moves forward between the rolls. A hole is opened up in the centre of the solid round, and this hole is enlarged by passing it over a piercer plug.

The pierced billet, or shell, is a rough and heavy walled tube. It is rolled to reduce the diameter and wall thickness. At the same time it increases in length. This method is used to make tubing not less than 65 to 70 mm in diameter.

Much ingenuity has gone into mills rolling shafts of variable section. A typical mill has three rolls, also set at an angle to each other, having mushroom-shaped caps at the ends. The billet is continually pulled between the rolls and a hydraulic system makes the caps now move apart and now approach each other, rolling the billet to a varying diameter in the process.

As variable-section shafts are very commonly used parts in modern machinery, the new process developed by a team of Soviet scientists under

Tselikov, a corresponding member of the USSR Academy of Sciences, is gaining ever more ground. A modification of the process is used to make rear axle shafts for the Moskvitch car. This change-over from forging to rolling saves as much metal over a year as is enough for several hundred cars.

As to steel wire, rolling can produce it down to 8 or 9 mm in diameter. Finer wire is made by drawing—a very ancient and a very simple process. For this, the rolled product is drawn through a die a bit smaller in diameter than the wire. As the reel revolves incessantly, the wire, ringing from tension, flows out of the die. It has a smooth and bright surface and a diameter accurate to a few hundredths of a millimetre.

You can use drawing for making thin-walled tubing, and a great variety of sectional shapes: squares, hexagons, octagons, ovals, half-ovals, half-rounds, triangles and flats.

Wire can be drawn as fine as 0.01 mm or even less in diameter, and tubing to a wall thickness of less than 0.1 mm. No other process can compare with drawing in making such products.

Years ago I spent hours watching rolling-mill operators at work at a plant in Moscow. To me, their job was full of beauty and thrill.

I can still see with my mind's eye a white-hot billet emerging from a reheating furnace. A pair of tongs grip it to put between the ruthless rolls. Gradually the billet grows longer and longer. Again and again the tongs, precise and resolute, throw it into the iron jaws of the mill. Soon it turns into a fiery serpent wriggling past the operator. It comes out and out from between the rolls, and its end vanishes below the cast-iron slabs of the floor. For a few moments it wanders somewhere in the basement to come out again. Now the serpent of fire dashes upon the operator, as if poising to strike, crush or burn him.

But the man is quiet. The rolls come down on the head of the serpent, and it again goes underground to return as two loops of white-hot metal.

As I stood watching the man, sure of himself and calm, engineers were telling me something about obsolete methods, new machines, and an early end to this back-breaking toil. Back-breaking it was, but beautiful too. To me, the worker at the rolling mill has since remained a symbol of man's power over metal.

IN THE SMITHY

Hammering is the oldest way of mechanically working metals. Probably, it's at least ten thousand years old. Anyway man first tried to shape gold nuggets, lumps of silver and meteorite iron by the only method he knew — the blows of his stone hammer.

For centuries the smith's trade was sacred with all nations. Ancient Greeks had the god Hephaestus who was a smith by vocation. The Slavs, before they were converted to Christianity, had also had a similar god, named Swarog.

At first smiths also smelted metals from ores and worked the precious metals. With time other trades took over smelting and jewel-making. Since then the blacksmith's trade has changed little—in principle, at least.

Of course, with progress in engineering ever bigger forgings, tens or even hundreds of tons in weight, appeared. Of course, no blacksmith's hammerman can do much about a ship's screw or a turbine's shaft, however strong he may be. This is why various hammers have come to the smithy— air-operated, steam, and hydraulic. Way back a chap who could wield a hammer sixteen kilograms in weight went as an excellent hammerman. Today the tup of a hammer weighs a ton or even more. The primitive tongs has given way to manipulators which have enhanced the strength of the blacksmith's hands thousand-fold. For all that, however, hammering has changed little in principle.

But—let us recall casting. It's only a bit younger than hammering, and sand casting has likewise changed little in principle. Yet fundamentally new casting processes have come along.

The same is true of forging.

How is hand hammering done? The smith thrusts a cold piece of metal into the white-hot belly of his forge and adds some more coke. The striker stands by, ready to wield his hammer. When the metal becomes hot enough, the smith snatches it out with a pair of tongs and places it on his anvil. Now the metal is in his power.

He may turn a long rod into a squatty barrel. For this he stands the rod on an end and shows the hammerer where to strike, and how strong. With every blow the piece is upset, or enlarged in section, more and more. Smiths call this operation upsetting.

Or he may pierce a hole in the metal. For this he puts the metal over an opening in the anvil and sets a punch against the opening. With several blows of his hammer, the striker makes a hole, and the "punch scrap plug", as smiths call the thing, falls onto the floor. This is punching.

Or he may cut the piece in two. Now the punch gives way to a chisel. Not the cold one used for benchwork, but one fitted onto a long wooden handle.

Now let's turn to machine hammering. Although on a greater scale, it uses the same principle: a piece of white-hot metal is shaped by a series of blows in quick succession.

A skilful smith can work miracles with the piece of metal lying before him on his anvil or under a steam-operated hammer. Yet forgings made by hammering are crude things. They need machining. Because of this, they

are made with extra stock which is later removed on a lathe or some other metal-cutting machine. Naturally, this involves wastage of metal. Even the improvement in the mechanical properties of the workpiece by hammering cannot make up for the loss. As a way out, related mechanical treatments have appeared around hammering, using the same principle—a blow or a squeeze.

One of them is pressing. Its principle is very simple. From hard and durable steels you make a die—an exact replica of the article you're going to produce. The die is placed under a power hammer or a forging press. Then a piece of metal—in sheet or rod form—is placed in the die. You press a button, and the tup of the hammer or the press goes down. The workpiece coming out of the die has a smooth surface finish and dimensions accurate to five parts in a hundred.

The metal can be pressed both hot and cold and formed either in a single blow or squeeze or in a series of them, when the workpiece goes from die to die, until it's given the final shape.

Pressing can be easily automated and run at a high rate of production. Automatic hot presses turn out as many as eighty pieces a minute, and cold presses over four hundred pieces every minute, or twenty-four thousand an hour.

Because of these and other advantages, pressing is gaining more and more ground from hammering. Ever bigger parts are being pressed, and ever bigger forging presses are being made.

We've already learned that the striker's hammer was seldom heavier than sixteen kilograms. The tups of power hammers do not weigh more than ten tons; even then their blows make the whole building shatter. Existing hydraulic forging presses develop a force of over sixty thousand tons, and units are being designed with a force of up to 200 thousand tons. Such a press will forge a plane wing or a car body in a single squeeze.

Now you can find for yourself how many times the steel muscles of these presses are stronger than the striker's hand they have replaced.

Still another member of the family of processes by which metals are wrought is extrusion. In extrusion the metal is made to flow under high pressure through a narrow orifice in a die, shaped to give the metal a useful form. At present, extrusion is applied to the non-ferrous metals, aluminium, copper, zinc, tin, lead, and so on. Steel extrusions are made from billets or rolled blanks.

A variety of shapes, tubing, and a multitude of small parts are made by extrusion. They are all superior to rolled products both in dimensional accuracy and surface finish.

Everyone has held a collapsible tube of tooth paste, body cream or paint, but very few, I'm afraid, know that the tubes are made by what is called impact extrusion. In the impact process a slug of soft alloy is placed

in a shallow die and given a blow by a punch or former. The metal is caused to flow up over the punch and through the annular orifice between it and the sides of the die. When a tube is made, the punch withdraws it from the die, a special device detaches it from the punch, and the tube goes to a filling machine.

Such are the close relatives—and chief rivals—of hammering. Yes, rivals, because pressing can, and will soon, oust hammering where forgings are made in great numbers. Hammering, that ancient art, will only remain where single forgings are needed.

Will the number of processes increase by which metals are wrought into useful forms? In all probability, yes. For hardly any one can say that all approaches have already been tried in this field and nothing better can be invented.

JOINING OF METALS

In his story, "The Artist", Vsevolod Garshin, a Russian writer of a great tragic talent, painfully sensitive to human sufferings, gives a depressing picture of work at a nineteenth century boiler-making factory.

"It's a hell of a job, I'll tell you. A helper climbs into a boiler and holds a rivet in his tongs, pushing hard at them with his chest, while a worker strikes at the rivet with his hammer from the outside.

"But it's the same as to strike at his chest!

"Yes, it is."

And in another passage:

"Here he was, sitting in front of me in a dark corner of a boiler, hunched up, covered with rags, and breathless from fatigue. I wouldn't have noticed him, but for the rays of light passing through the holes drilled for rivets. The circles of light were strewn over his clothes and face and shone like golden spots on his rags, his unkempt and sooty beard and hair, his reddened face greased with sweat and dirt, his knotty, overstrained arms, and his broad but exhausted and hollow chest. Time and again a terrible blow came down on the boiler, making the poor devil do all he could to keep himself so perched up."

Anyhow it was hardly possible to make boiler-making easier. Riveting was the only way of joining metals together. Welding was still far off at that time.

Tsiolkovsky, working on his design of an all-metal airship, specified brazing for the hull. He hardly thought it appropriate to fabricate that wonder of engineering, the airship, by blacksmith or forge welding, the only welding process known in his time, the most primitive one and of limited use.

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To see how it's done, imagine you're in a poorly lit smithy, with the forge at full blaže. The smith, in a sack-cloth shirt unbuttoned at his neck and with an ash-smeared and burned-through apron on, snatches out a white-hot piece of metal and puts it on his anvil. His helper places another piece over it, and a series of blows follows, welding together the workpieces. This is forge welding. It is still being used.

Gradually other welding processes came into being, such as arc welding, gas welding, friction welding, and so on.

INVENTORS OF IRON STITCHES

Arc welding was invented in Russia. One of its varieties, known as carbon-arc welding, was originated by Nikolai Bernardos. Sometimes it is termed so—the Bernardos process.

Bernardos was born in the family of a career officer in 1842. However he did not follow the family tradition. In 1862 he enrolled with the Medical Faculty of Kiev University. Yet it was not medicine that he devoted all his life to. He chose the thorny road of an inventor.

He made over one hundred inventions during forty years since 1865. Very few people are fortunate to add so much to man's treasury of knowledge and skills as he did. His major invention was carbon-arc welding.

Another variety of arc welding was the metal-arc process invented by Nikolai Slavianoff, also of Russia. True, he thought of his invention more as of a "method for electrically casting metals" and pictured it as an operation by which the molten metal of the electrode would fill moulds. Later he suggested the preheating of the workpieces so as to improve the quality of welds and was the first to use fluxes. In 1927 his idea was carried a step farther by the engineer Dulgevsky who suggested to weld metals under a blanket of powdered material.

Arc welding is a miraculous thing. The welder holds in his hand a metal rod. You can see nothing unusual about it until it touches the edge of the metal to be welded. Then an electric sun flares up under the welder's hand. As a protection to his eyes and face against burns, the welder puts on coloured goggles or a face shield. But the most amazing thing about arc welding is the result. The two pieces of metal are joined by a neat seam like the one a skilful seamstress makes on clothes.

Today these metal seams can be seen everywhere, on railway wagons, bridges, cranes, and skyscrapers.

The temperature of the arc burning at the end of the electrode is 2400-2600°C. It melts both the electrode and the parent metal. The molten metal fills the depression forming in the joint at a given moment. As the arc moves

on, the metal solidifies and forms the weld. All is done at a fairly high rate. An ordinary electrode 45 cm long is melted within two minutes; a weld six millimetres high and twelve centimetres long is completed inside one minute.

According to scientists, a riveted joint with an area of 56 square centimetres, supporting a load of 62 tons, needs eleven rivets. This involves the expenditure of 1.72 man-hours, as against the 0.71 man-hour required to make a welded joint of the same area and supporting the same load. Thus, even manual arc welding more than doubles labour productivity and saves much metal.

Arc welding, however, is not only a substitute for riveting; it can be used where riveting is out of the question. You can't, for example, butt-rivet two sheets of metal without straps. But this can be done by arc welding. You can't rivet a patch over a hole in the hull of a sunken ship. But this can be done by arc welding. Yes, the arc can do its job even under water. As it burns, a bubble of steam and gas forms, breaking away and floating to the surface all the time, but still reliably protecting the arc and the molten bath. The underwater arc-welding technique has been developed by K. Khrenov of the Soviet Union.

Manual welding is a highly skilled operation or even an art. Should the welder move the electrode too far from the workpiece, the arc will die out, and the metal will cease melting. Should he move it too close to the metal, the arc will again go out, and the electrode will freeze to the work as a mournful reminder of poor skill. It can only be broken away or cut off with another electrode guided by a more experienced hand. Not just any one, and not overnight, can learn the knack of making good welds. No machine can, it would seem, replace man at this.

Still there are automatic welding machines which operate better, faster and more accurately than the best welders. In the Soviet Union they were developed at the Paton Electric Welding Institute under the guidance of the scientist whose name the Institute bears.

Automatic welding machines ordinarily use a blanket of flux—a process known as submerged arc welding. The operator sets the voltage, current and speed, and the welding head starts moving over the joint which may be horizontal or vertical. It sprinkles the joint with flux which fuses into a dense and strong crust protecting the metal stitch of the weld from atmospheric air or, which is the same, oxidation. The weld is built up ten to fifteen times faster than in manual welding. In some cases an inert gas is used to give protection to the weld.

Not that manual welding has dropped out of use. While automatic machines reign supreme on long, straight seams, manual welding is the principal, if not the only process where welds make up fancy patterns or consist

of short runs. To make manual welding more efficient, electrodes are covered with fluxing or other materials. Some go over into the weld metal to improve its quality, others form a crust of protective slag. Sometimes the welder uses a cluster of electrodes, each made of a different metal.

The electric arc can weld steel, cast iron (with a preheat of 550-650°C), copper and aluminium. For each of these metals there is a specific welding technique and procedure.

Arc welding is not the only welding process using electricity. As common is electric resistance welding. It works as follows.

Suppose you have to join together two steel sheets. That could be done with a double row of rivets. Instead, you feed the sheets into a machine, the top platen comes down to clamp them, and fifty copper studs touch the work. In less than a minute the copper studs come apart, you take out the sheets and see them welded together at fifty spots. And this is how the process is called —spot resistance welding.

The copper studs, or electrodes, carry a heavy current. Where they touch the metal, the temperature rapidly rises. The electrodes apply pressure, and the sheets are welded together. Spot welding is a fast process. A spot welding machine can make over ten thousand spot welds an hour.

Instead of spots other machines make continuous, or seam, welds. Seam welding machines operate on the same principle as spot welders, but instead of stud electrodes they have disk or wheel electrodes. As the sheets travel between the wheels, they are heated at the point of contact, and the pressure completes the job. Seam welding
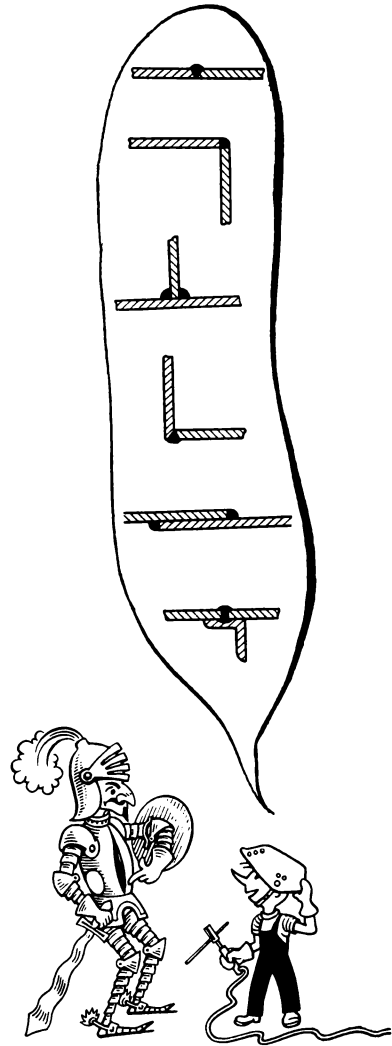
Welded joints are many

machines make five to six metres of weld every minute—a very high rate!

Still another variety of resistance welding is the butt process. The parts to be welded are clamped in jaws holding them tightly to each other. A current is turned on. Naturally, the resistance to current flow is greatest at the joint. The metal is instantaneously heated to a pasty state, the pressure on the parts is increased, and this completes the weld.

In some applications the flame of a gas is used as a source of welding heat instead of electricity. It melts both the parent metal and the filler rod. The gas is usually acetylene, the same acetylene which was once used in miners' lamps. It is produced from calcium carbide. Natural gas, hydrogen, petrol and kerosene can also be used for the purpose.

The temperature of the flame coming out of the gas torch is about 3000°C. The welder holds the torch in one hand and guides the filler rod with the other. In the tiny welding bath the weld joining the workpieces is made under his hands.

A related process is gas-pressure welding. It comes in especially handy in the erection of cross-country pipelines. The pipes to be welded are aligned end to end, the joint is heated to a pasty state, and the ends are pressed together to complete the weld.

The gas torch, sharp as a knife, can be used not only to join but also to part metals. This is known as gas cutting.

Standing apart from all other welding processes is thermit welding.

Suppose rails are being laid for a tram-line. The rails must be so joined that no gaps are left between them. A crew of welders is called in. They have with them neither a transformer for electric welding nor acetylene cylinders for gas welding. They put a strange-looking iron box called the mould, lined with refractory clay, on the inside over a rail joint and set up a similar funnel, or the crucible, on the box. They pour some powder into the crucible, put a burning match to a starting cartridge, and in an instant the crucible turns into a miniature volcano with a wild flame and gurgling lava. This lasts only for a few seconds. A half-hour later the workers take apart their fixture. The rails are reliably joined together. The only thing left now is to remove surplus metal and slag.

The powder that the welders put into the crucible is a mixture of finely divided aluminium and iron oxide. The mixture is called thermit. On burning, the aluminium is violently oxidized and the iron oxide reduced. The temperature rises to 3000°C, melting the mixture and producing thermit steel. The aluminium oxide floats to the surface as a crust of slag, and the steel flows down into the iron mould surrounding the rail joint. The steel

joins the base and web of a rail, and the slag heats the rail head to a plastic state. Pressure completes the weld.

Generally speaking, any two pieces of metal placed in contact must form a bond. This is because metals are capable of diffusion into each other, in much the same way as a salt in water. Under ordinary conditions, however, this does not happen. Apparently the film of oxides covering the metal stands in the way, scientists concluded when they took up the matter for the first time. So the problem was to eliminate the separating film.

The investigators placed the pieces to be joined in a vacuum. In a vacuum there is no oxygen to sustain oxidation, and no oxide film can grow. To speed up the diffusion, they heated the workpieces by high-frequency current. In a few minutes they took out the work—the weld was strong and sound, although there had been neither the sputtering of molten metal nor an electric arc or sparks, those familiar companions of welding, because the temperature of heating was much lower than in any other welding process. When a section of the bond was examined in a microscope, the researchers saw that the metals had dissolved in each other at the interface.

Before long the new process, called diffusion welding, found a broad field of application. Of course, it isn't reasonable to join a bridge girder by this method, but it will join a cermet tip to the shank of a cutting tool better than any other method.

· Diffusion welding is equally good at joining steel and chromium, aluminium and copper, nickel and iron. It has proved the cheapest process of all, because it needs neither electrodes nor fluxes. In the Soviet Union it has been introduced by N. Kazakov, M. Sc. (Tech.).

I have on my table before me a broken titanium rod. It's a memento of my visit to Kazakov's laboratory. The rod was cut in two and then welded by his method. After welding, the rod was pulled in a testing machine—the metal broke at a place other than the weld. Such is the quality of the new process.

Today a total of about 120 welding processes are in use, and they are growing in number all the time. The space we have is not enough to cover them all. Yet two of them deserve mention. One is friction welding and the other ultrasound welding.

The first was run into by A. Chudikov, then a beginning lathe operator, in 1956, when he was turning a steel part. He did not notice the smoke of burning oil at the tailstock centre. When he tried to remove the machined part, he couldn't. The part had frozen to the tailstock. "What if I try to weld this way," the young man thought. "It seems very handy, with no electric current or gas to use."

And he tried. At first in his shop, and then in the laboratories of the USSR Institute of Electric Welding Equipment. That's how friction welding came along.

Suppose you are to weld together two lengths of piping. You clamp a metal ring between the pipe ends and begin rotating it at high speed. The friction heats the joint, and the metal grows pasty. Now you stop the ring and compress the joint.

This method may prove useful in laying gas pipelines and in the fabrication of reinforced-concrete products. The friction weld is very sound and its cost is only one-tenth of any electric weld.

The other promising process is ultrasound welding. In it, ultrasonic oscillations do the job of both the electric arc and the flame of a burning gas. It is probably the only method by which two sheets of aluminium foil can be joined. While they will immediately shrivel up and burn or evaporate in the arc, or the scorching heat of the acetylene flame, ultrasound will do them no harm.

In ultrasound welding, the sheets of metal are placed under a rod connected to an ultrasonic transducer. Within its range of action, ultrasound causes the metal particles to oscillate and diffuse between each other. At the same time, the oxide film, if there is any, disappears. The metal, although it rises little in temperature, comes by increased plasticity and welds well.

Ultrasound can make spot, stitch and seam welds in sheet material up to 1.5 mm thick. What is especially attractive about ultrasonic welding is that it can weld not only metals, but also many plastic materials.

Usually it takes a split second to complete an ultrasonic weld. It is only in rare cases that the operation lasts six "whole" seconds. Even then it is much faster than any other process. Another advantage is that the joint need not be scratch-brushed or otherwise prepared for welding.

Such is the art of welding as it stands today, covering the fabrication of huge turbine frames, motor cars, cross-country pipelines, bridges and hundreds of other products. It has replaced less reliable soldering and brazing in many cases and has made feasible what was impossible at all before its advent.

At its cradle we can see three Russian scientists—Petrov, Bernardos and Slavyanoff. The credit for its wide-spread use today, however, is due to many people—outstanding scientists and talented inventors, who have put much thought and effort into it. But we can't say we have learned everything about it. Cast iron, for example, can only be welded with difficulty and

under special conditions. A good deal of trouble is encountered in welding alloy steels. Manual welding is a slow job. A host of puzzles are still awaiting an explanation in the bath of molten weld metal where intricate metallurgical processes take place.

METAL AGAINST METAL *

We've spoken of metal-cutting derogatively more than once. For all its drawbacks, however, it remains one of the principal methods for working metals. Metal-cutting machines take up whole departments at any engineering works. They are made in a large variety of types, sizes and applications.

The vertical turret lathe is a huge thing, for example. Its revolving table is large enough to hold a country house. You must be a strong man if you want to lift its cutting tool single-handed. In contrast, the watchmaker's lathe is the size of a sewing machine and uses tools no bigger than a needle.

Although called differently —turning, screw-cutting, planing, drilling, boring, milling, grinding or broaching — all of these machines work metals by removing surplus stock as chip. The chip may be so small as to be visible only in a microscope; such chip is removed by the grinding wheel. Or it may be a slug of metal two fingers thick; such chip is removed by the tool of a big planer. Still it is chip. The major trend in machining is to remove as ever more chip as possible within the same time, that is, work, at high speeds of cutting.

What is it that stands in the way of a greater speed? Above all, it is the durability of the cutting tool. The tool must be harder than the blank, or its cutting edge will be blunted or broken in no time.

It isn't difficult to select an alloy which is harder than the metal to be machined. There is a large group of tool steels which, when quenched, are hard enough to cut metals. But they do so slowly.

The reason is this. In cutting, friction generates much heat, the blank and tool grow hot. The bright surface of the chip is tarnished at once, and temper colours develop on it. You won't be able to touch it —it's very hot, as if it came straight from a furnace. It's this heat that hampers faster cutting. On heating, the metal of the cutting tool loses much of its strength.

The easiest way to control tool heating is cooling, and it's widely used in metal-cutting machines. As the tool moves along the work, a jet of cutting fluid trails behind. It strikes right at the place where the tool and the blank come in contact and cools it. With cooling the speed of cutting can be raised one-quarter to over one-third.

Another approach is to make cutting tools from materials which do not soften at high temperature. This has been done for over a half-century.

Until the end of the 19th century cutting tools had been mainly made of plain carbon steels. They lose their cutting properties at as low as 225°C. Because of this the speed of cutting was seldom greater than five metres a minute.

Early this century the first qualitative jump took place —cutting tools came to be made of alloy steels containing chromium, tungsten, and molybdenum. The cutting edge of such tools stands up well to heating as high as 600-650°C. With them the speed of cutting was increased four to five times. Such steels are now known as "high-speed" —the chip runs from beneath the tool at up to 30 metres a second.

Another advance in cutting speed was due to sintered or cemented carbides, sometimes called "hard metals".

For the first time tungsten carbide was prepared in 1893. It was nearly as hard as diamond—a property which attracted engineers at once. Naturally, they immediately thought of using it as a material for cutting tools.

This was not, however, easy to do. Tungsten carbide is brittle. To overcome this, powdered tungsten carbide was mixed with powdered cobalt. The mixture was compressed into an insert for the cutting tool, and was heated to the fusion temperature of cobalt. As a result, the cobalt had bound together the grains of tungsten carbide, and the material had lost much of its brittleness.

In the Soviet Union "hard metals" came into use about 1929. Cutting tools made of them kept working well heated to 900°C and at a speed another four to five times greater.

Then came ceramics (or cemented oxides), those relatives of clay jugs and brick. Not that they were easy to adapt to a new job—to cut metals. The first ceramic or cemented-oxide tools went into use about 1950. The ceramic tools used today can work successfully at a temperature of up to 1200°C. In most cases, the principal ingredient is corundum, or oxide of aluminium, which is nearly as hard as diamond. It melts at 2050°C. With ceramic tools, the speed of cutting has risen to 1,000 metres a minute. Thus, over a half-century the speed of cutting has increased 200-fold.

CUTTING BY A SPARK

As legend goes, the Queen of Sheba and King Solomon, those great sages of ancient times, liked to test each other's wit by asking baffling questions. One day she gave the king a gem with a tortuous hole drilled in it.

"Try and put a thread through the gem, o wise king", she said.

King Solomon was quick to guess what to do. He took a silkworm and put it into the hole. The silkworm made its way through it, pulling its silk thread behind.

"Here's your gem with a silk thread put through it," King Solomon told the Queen of Sheba when the silkworm had come out.

Clever as he was, however, King Solomon would have been put hard to it if the queen had asked him to make such a hole in the gem. In fact, this was an insoluble problem to the engineer a mere twenty years ago. Today you can easily make a curving passage in the hardest of metals. But again, it must not be circuitous, or you won't be able to use a cutting tool. This is still a problem which the engineer cannot tackle by metal-cutting alone.

There are other jobs which a metal-cutting machine can do with difficulty, if at all. For example, it cannot make a hole 0.02 mm in diameter in a piece of tungsten carbide or a slot the shape of an 'X' in hardened tool steel. At this, metal-cutting has today been replaced by another process. In the Soviet Union it has been pioneered by Mr. and Mrs. Lazarenko. Instead of a cutting tool, their process uses an electric spark and is known, therefore, as spark machining. As Mr. Lazarenko confessed to me, his wife and he had never thought of metal-working. Their concern had been the destructive action of direct current on contacts in relays and other electric devices. The action tended to eat away one contact in the pair and build a mound on the other. It looked as if the sparks striking between the contacts carried over metal from one to the other.

When they looked into the matter closely, the Lazarenkos realized that the sparks, if made strong enough, could be used to machine metals.

Today spark-machining units can be seen at work at many factories. Dozens of tool-makers the world over are manufacturing them.

In spark machining, tool and workpiece are separated by a small gap and are kept dipped in a fluid which does not conduct current, such as water or paraffin. The tool makes one side and the workpiece the other side of an electric circuit. Metal is removed from the workpiece (and to some extent from the tool) by a rapid succession of sparks. The face of the work is eroded opposite the convexities of the tool until the contours match. A servo mechanism maintains the gap constant.

Slowly the tool eats its way into the metal. "Slowly" is not an exact word, though. For the metal is a very hard steel in which the best drill cannot make so much as a dent. It cuts two centimetres every minute, which is not bad at all.

The tool, or rather the electrode, is usually made of copper or brass, although other materials are also being tried. It can be machined or cold-formed to any shape and any size. It can be made very fine so that a hole five microns in diameter, or one-tenth as thick as a human hair, can be cut. It can be so shaped that a most fanciful groove can be made. More important still, it can work any metal, however hard it may be.

Engineers have not been fully satisfied with "straight" spark machining in which the sparks are produced by switching a direct current of the

correct voltage. One reason is that too much energy is taken up, and another is that on soft metals the process has proved slower than conventional metal-cutting.

So a modified circuit has been added which produces pulses of electric current following at a very high rate. As a result, for an average quality finish the cutting rate has gone up five to six times, tool wear has been drastically reduced and energy consumption cut down.

Electricity comes in handy in a great many other machining processes. The simplest among them is electric-resistance cutting. The workpiece is made one side and the tool, which is a smooth-rimmed disk, the other side of an electric circuit using alternating current. The place of contact between work and tool offers high resistance to current flow, and the metal is heated to a pasty state. On rotating, the disk makes an easy cut through the metal. In this way rolled shapes and pipes are cut and bearing balls are machined.

A more sophisticated process is electrolytically assisted machining. In fact, it uses a very simple principle. As in electric-resistance cutting, the workpiece is connected to one side of an electric source and the tool to the other, but instead of alternating current it uses direct current. The place of contact between the two is continually sprayed with an electrolyte, so that a conducting path is formed for the current through the cutting zone. The current dissociates the metal, the tool removes the film thus formed, and more metal is exposed for the current to destroy it electrochemically.

Electrolytically assisted machining can be used to cut and polish metals. In cutting, the tool is a smooth-rimmed disk which removes the film of oxide formed by electrochemical action. The production rate is more than half as high again as in mechanical cutting at half its cost.

In electrolytically assisted polishing, the grindstone is held to the work, the electrolyte and current dissolve the surface layer of the metal, and the stone removes it. For the same quality of finish and precision, the production rate is five to six times as high as in mechanical polishing.

High surface finish can also be obtained by purely electrolytic polishing. The object to be polished is made the anode in a suitable electrolyte, and a current is passed through the circuit. Rough spots on the work pass into solution under the action of the current, and the surface becomes ever smoother and brighter.

On the whole electrical machining is just coming into commercial use. Yet, it can already show much for it. With further improvements it will be gaining more and more ground from mechanical processes.

6

THE FLYING METALS
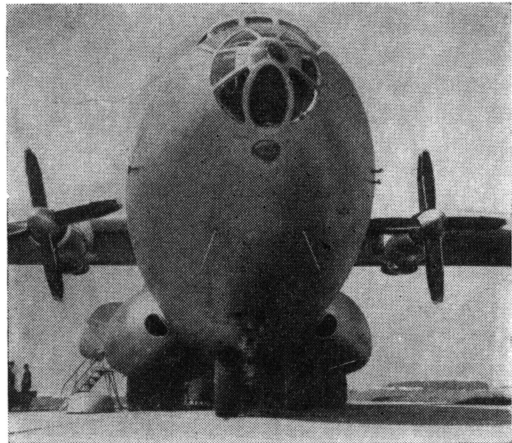
Aluminium was first isolated by Oersted of Denmark in 1825. It was up to 1845, however, that Wöhler of Germany had been able to get enough aluminium to determine most of its properties. Its properties were so attractive that scientists in many countries made attempts to develop commercial processes for its manufacture. Finally, in 1854, Deville of France came out with the first commercial process for the production of aluminium. In Russia research was conducted by Beketov. In 1865 he experimentally proved the feasibility of a process which came to be used at the aluminium works at Gmelingen, Germany, in the 1880's.

For all this progress, however, aluminium remained a very costly metal until 1886, when Héroult in France and Hall in the United States independently patented a process which ousted all other methods from the field. Since 1888 their process has become a regular industrial practice.

There is no denying, aluminium is a 20th century metal, the metal of high-speed cars, supersonic planes and space craft. Yet, as far as legends go, it was known to ancient people.

To believe the Greek philosopher Plato, the inhabitants of Atlantis knew one more precious metal in addition to gold and silver. From the brief description of its properties he gives, the metal looks like aluminium. It's anyone's guess, however, how the ancient people made it.

Pliny the Elder, another ancient historian, tells this story. About two thousand years ago an unknown master came to see Tiberius, the Roman emperor who was born in 42 B.C. and died in 37 A.D. The master gave the emperor a metal bowl, light in weight and bright as silver. The master said he had obtained the metal from clay. Afraid that the new metal might devaluate his reserves of gold and silver, Tiberius had his men cut the master's head off and destroy his workshop.

The chances are the metal bright as silver and very light in weight was aluminium. But these are only tales.

Aluminium, as we know it, is a product of electrical engineering. Without electricity it could not have been obtained until today. In any case aluminium owes its status of an engineering material to electricity.

Aluminium is a metal that has boosted the progress of aviation. It has turned the primitive wooden structures of the Wrights' era into supersonic jets and huge turboliners.

In addition to electrical engineering and aviation, aluminium is closely related to other, more recent industries. This is why its production is expanding all the time. A century ago all the aluminium produced could be weighed in kilograms. In 1897 its manufacture rose to 4,000 tons, and in 1913 to 66,500 tons. In 1943 its world output (outside the Soviet Union) was 1,949,000 tons. At the time of writing, close on three million tons was produced in the world outside the socialist system.

Although Russian scientists did a good deal of research, the commercial production of aluminium in the country began only after the October 1917 revolution. On March 27, 1929, the first eight kilograms of aluminium were prepared, and in August the same year the government took measures to build aluminium works at Volkhov and on the Dnieper. The Volkhov Works went into operation in 1932, and the Dnieper Works in 1933.

In 1939 Europe's biggest aluminium works was commissioned in the Urals. But already in 1937 the Soviet Union ranked third in the world and second in Europe in aluminium production. Since then the production of aluminium has been expanding in the Soviet Union at a steady rate.

NOT A POOR RELATIVE

As to abundance, aluminium ranks first among all metals and third among all elements after oxygen and silicon. It comprises 7.45 per cent of the weight of the Earth's crust. Academician Fersman, the famous Soviet geologist, identified about 250 minerals containing aluminium. But nobody has ever found a piece of native aluminium. Because of its high reactivity, aluminium occurs in nature only in compounds.

If it is so reactive, why is it that aluminium does not burn in air like potassium?

As a matter of fact, it does begin to "burn", that is, oxidize. Its shiny surface grows dull at once, and a film of oxide forms on it. But the oxidation stops there. The oxide film is very strong and tenacious. It serves as a sort of armour for the weak metal.

Because of this film of oxide, aluminium has a high resistance to some aggressive liquids. Concentrated nitric acid and organic acids can do nothing to it. But alkalis will dissolve the film, exposing the underlying metal to destruction.

Commercial aluminium containing not over five parts of impurities in a thousand melts at 658°C and boils at 2500°C, remaining as a liquid over a range of nearly two thousand degrees.

Aluminium is a lightweight metal. Its specific gravity is 2.7, or one-third that of steel (7.8).

Aluminium is a soft metal. It can be easily rolled, cut, drawn, forged, and so on. But it lacks strength. The ultimate tensile strength of commercial cast aluminium is three to twelve kilograms per square millimetre. Its strength, however, can be improved by rolling. Rolled aluminium sustains a load of 18 to 28 kilograms per square millimetre without breaking. Unfortunately, rolling impairs its elongation, which is a measure of a metal's ductility. Cast aluminium has an elongation of 18-25 per cent, and rolled aluminium only 3-5 per cent. By way of comparison, plain carbon steel containing about three parts carbon in a thousand has an ultimate tensile strength of 45-50 kg per square mm and an elongation of 20 per cent.

Aluminium has a high conductivity for heat and electricity. It ranks third among all metals in this respect, following copper. Depending on its purity, the electrical conductivity of commercial aluminium is about two-thirds that of copper's.

Yet, although it is inferior to steel in strength and to copper in electrical conductivity, aluminium is not a poor relative in the family of metals. Simply it must be looked at from another angle.

We shall leave out—for the time being—aluminium alloys, some of which compare favourably with mild steel. Let's examine the properties of ordinary wrought aluminium.

We make from it a round bar as long and heavy as a steel bar one square millimetre in cross-section. Of course, the aluminium bar is thicker than the one of steel, but both have the same weight. First test them for tensile strength.

The steel bar breaks as soon as the load exceeds 40 kilograms. This is the strength of a good structural carbon steel which goes to make bolts, screws, girders, and like parts.

Now we load the aluminium bar. At first the load is twenty kilograms, then fourty kilograms. Finally, when the load is sixty kilograms, the bar snaps. It turns out to be half as strong again as the steel bar.

In other words, wrought-aluminium girders of equal strength may be made a third lighter in weight, fewer piers will be required and longer spans may be used in an aluminium bridge. A TV tower, if made of aluminium, may be taller than one made of steel. Aluminium wagons of the same strength will carry a bigger payload than steel ones. From this comparison aluminium emerges a successful rival to, rather than a poor relative of, steel.

If we compare aluminium and copper wires, we shall see that an aluminium conductor with the same resistance to current is lighter in weight than one from copper. Fewer supports are needed for a power transmission line, and a motor or a generator with aluminium windings is lighter in weight.

From these advantages stems the popularity of aluminium as a material of engineering. Electrical engineering uses it in the form of wires, cables and busbars, in capacitors, rectifiers and instruments. Radio engineering uses aluminium foil as thin as tissue paper and aluminium wire finer than cobweb. Chemical engineering utilizes the high corrosion resistance of aluminium in apparatus for the production of nitric acid, many organic substances and foodstuffs.

A lot of aluminium is used in cars, buses, and railway wagons. Aluminium also goes to make furniture, light in weight, strong and attractive.

Yet the biggest user of aluminium is aviation. Most modern planes the world over are made of aluminium.

As time passes, ever more uses are found for aluminium. The only thing that prevents it ousting steel from all jobs is its cost, which still remains high.

THE BIRTH OF ALUMINIUM

As far as appearance is concerned, an aluminium works has nothing in common with an iron and steel works. It has no blast or open-hearth furnaces, no blooming mills. Instead of the burning coke, the metal is born in a hot electrolytic cell through which electricity flows in quantities sufficient to produce a lightning. Like the blast furnace, the electrolytic cell is the focal point of many steps in the process.

One such step is the production of pure alumina.

Alumina is an earthy mineral which is essentially an oxide of aluminium. It is present in all slates, clays and shales. In the pure state it is found very often as blood-red ruby, sea-blue sapphire, "oriental" topaz (which is yellow sapphire), violet "oriental" amethyst, and green "oriental" emerald.

They are all oxides of aluminium with an admixture of some metals which impart the particular colour. Each could be used as a source material for the production of aluminium, if they were not so rare. Instead pure alumina is obtained from several "ores": bauxite, nepheline, alunite, kaolin and cyanite.

The most important source is bauxite, an earthy or stony material which is a mixture of hydrated aluminium oxide, iron oxide, hydroxide and silicates, quartz, titanium compounds, and also small amounts of sodium, potassium, zirconium, chromium, phosphorus, vanadium, and gallium. The explored reserves of bauxite in the world are estimated at over a thousand million tons, mostly in Europe, less in Africa and very little in America and Asia.

Huge deposits of bauxite have been found throughout the Soviet Union: near Tikhvin (Leningrad Region), the northern Urals, the southern Urals, the Krasnoyarsk Territory, and elsewhere.

Bauxite ores differ greatly in specific gravity, colour and chemical composition. If you were shown two lumps of bauxite, one from Tikhvin and the other from the southern Urals, you wouldn't know they are the same mineral. Even within the same deposit bauxites may be altogether different. The Tikhvin grades, for example, range from white to red and violet in colour. This diversity in appearance and physical properties handicaps prospecting for bauxites.

Alumina can be prepared in several ways. The most common are alkaline processes. Here is how one of them is carried out.

Heavy trucks dump their loads of run-of-mine bauxite into jaw crushers. Lumps forty to sixty centimetres across are reduced to the size of cobblestones. Then the ore is further reduced in size in cone crushers and is finally wet-ground in ball mills. From the ball mills the raw pulp goes to autoclaves or digesters to be leached, or digested.

An industrial autoclave is a strong steel vessel as tall as a three-storeyed building and up to three metres in diameter. It is built to withstand high pressure at a temperature of up to 250°C. The raw pulp for the autoclave, consisting of ground bauxite and alkali, is digested for several hours, while the pulp is being stirred by live steam. Rising to the surface, steam bubbles heat and stir the pulp.

The chemical side of the process is very complicated. The alkali reacts with the aluminium oxide and the other components of the ore. Some of the products of the reactions further react with each other. Most of them, however, are left as a residue. The valuable product of the process is a solution of sodium aluminate sometimes carrying small quantities of compounds of silicon, phosphorus, chromium and some other elements.

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The digesting treatment is a process calling for careful control. Its run may be spoiled by many factors, such as the composition of the bauxite, the concentration of the alkali, the dwelling time, temperature and pressure in the digester. Sometimes you may find it impossible to complete the digesting treatment in a single autoclave. Then a battery of digesters has to be used, operating on a continuous basis. Whatever the technique, however, high skill and experience are essential, if you are to get as much as 85 per cent of the alumina out of the source bauxite.

From the digester the pulp is discharged by steam pressure into a steam separator. In the separator the pressure drops and the pulp boils violently. When the boiling ceases, the pulp is cooled and diluted with wash waters.

The diluted pulp is run into a settling tank, or thickener, for the separation of the slime (known as "red mud") from the aluminate solution. To speed up the operation, a coagulant (such as rye flour) may be added to the liquor.

Before it goes to a waste dump, the red mud from the thickeners is thoroughly and repeatedly washed (this is where wash waters come from for pulp dilution) to remove the last traces of the aluminate. The overflow is filtered and then goes to a precipitator (or decomposer), a huge tank with a mechanical stirrer. In the precipitator the sodium aluminate decomposes of itself, leaving hydrated aluminium oxide as a residue.

Precipitation, which begins with the liquor having a temperature of about 60°C, may be carried either continuously, in a series of decomposers connected by siphons, or intermittently, in a single tank. In either case, it may be speeded up by addition of freshly prepared aluminium hydroxide which produces the seed —a multitude of crystallizing nuclei throughout the solution. Usually the operation occupies three to four days.

The liquor left after precipitation still contains much aluminium. It is not wasted. The liquor is returned to the process (this is why it is called recycled or return liquor), and is added to the ball-mill charge and the raw pulp fed into the digester. At the end of another cycle it gives up some more aluminium hydroxide, and so on.

After precipitation the hydroxide is classified into fines which are returned to the process as the seed, and a coarse fraction which is thoroughly washed, filtered and calcined.

The purpose of calcination is to drive off all the water from the aluminium hydroxide and produce practically unhygroscopic alumina, that very alumina which makes up the semi-precious stones ruby and sapphire.

Calcination is carried out in a rotary kiln, a huge inclined drum fifty to seventy-five metres long and about two metres in diameter. The lower, or "hot", end of the kiln fits into a fire hood where nozzles squirt a liquid or gaseous fuel. The raised end enters a flue from which the products of combustion escape to the stack and aluminium hydroxide is continually charged

into the kiln. As the kiln is rotated the material slides down the incline against the current of hot gases, giving up its water.

Calcined alumina is turned to aluminium by electrolysis. It is not easy to do. The material is very refractory —it melts at 2050°C, a temperature hard to obtain in an electrolytic cell. If direct electrolysis of molten alumina were used, aluminium would be really a precious metal. Fortunately enough, a round-about way has been found. Calcined alumina is dissolved in a suitable material, and the solution is electrolyzed with ease. The material is cryolite.

Cryolite is also an aluminium-bearing compound. In addition, it contains sodium and fluorine. It is found in nature, but the only commercial source of cryolite is in south Greenland. Natural cryolite has a symbolic appearance, for it looks like ice. A lump of cryolite placed in a glass of water is almost invisible. The Eskimos in Greenland at one time thought cryolite was ice compressed so much that it would not melt. Sometimes, by the way, cryolite may be snow-white, pink or even black, depending on the impurities present.

The scarcity of natural cryolite has spurred the preparation of artificial cryolite from fluorspar in many countries.

Fluorspar is a more common mineral. In the Soviet Union, huge deposits of fluorspar have been discovered in the Lake Baikal area and Central Asia.

As in the preparation of alumina, the first step is to grind the fluorspar. Then the ground material is concentrated and mixed with strong sulphuric acid. The mixture is heated in a rotary kiln where the fluorspar and the acid react at about 130°C. The treatment produces hydrogen fluoride, a very poisonous gas, and gypsum. The gas is drawn off through a flue and lead pipes for purification and the gypsum is discharged from the furnace by screw conveyors.

After it has been purified, the hydrogen fluoride is dissolved in water in lead towers, giving a solution of hydrofluoric acid. It is a very aggressive acid, attacking even glass. Incidentally, all inscriptions on glass are etched with hydrofluoric acid. Lead is one of the few materials it cannot destroy. This is why the towers for hydrofluoric acid production are made from lead.

The acid is treated to remove the impurities and is mixed with the aluminium hydroxide that has been prepared by precipitation from the aluminate solutions and calcination, and with soda. A chain of reactions follows, and a residue is thrown down. This is cryolite.

The whole process is carried out in iron vats lined with carbon blocks and fitted with stirrers. The pulp carrying the alumina and the sodium carbonate (soda) solution is fed into them in a continuous stream. Utmost care is taken to keep the ingredients in precise proportion.

Next the cryolite pulp is thickened, the solid particles are separated from the liquid in filters, and the solid material is dried in drum driers at 130° to 140°C.

That is how artificial cryolite looking like the unmelting ice from Greenland is made. Then it goes to meet alumina in the electrolytic cell. But there is one more participant in their meeting—the carbon electrode.

At first glance it might seem there is nothing particular about the cylindrical and rectangular blocks of carbon that are used in the bath of molten cryolite and alumina. However their manufacture is a delicate and complicated process carried out at specialized factories. All that goes to make an electrode finally finds its way into the cell. Therefore all the materials must be very pure so as not to contaminate the metal. Also, they must be good conductors of electric current, and have high density and mechanical strength.

We shall not go into every detail of the process, which covers a long way from the source materials such as anthracite, petroleum coke, pitch coke and coal tar, to the finished electrode and involves crushing the source materials, roasting, grinding, classification, proportioning, batching, compacting, and baking. After baking the electrodes are ready to be used in the electrolytic cells of an aluminium works.

A more recent trend has been to use "self-baking" electrodes, that is, electrodes which are baked in service. But it is every bit as difficult to prepare the materials for them.

In the electrolysis department you can see huge cells standing one next to another. In them electric current picks aluminium literally as single atoms in the molten bath of cryolite and alumina covered by a thick crust of cryolite. The metal collects on the bottom. The bottom (made up of carbon blocks to which current is conducted by steel rods embedded in cast iron) serves as the cathode of the cell. The carbon electrodes fed in from above are the anodes. Oxygen is continually evolving at them, and they burn.

The cell operates at not over five volts. But the current is very strong, rising as high as 15 kiloamperes in some of the cells. A huge stream of electricity flows through the molten bath, washing atoms of metallic aluminium out of it and depositing them at a single place. This stream of electricity would be enough to produce a continuous play of lightnings. In fact, it becomes sometimes visible, with small arcs striking around the anodes. This "anode effect", as it is called, is a reminder to the operator that he should add a fresh charge of alumina to the cell to keep it going.

We remember that pure alumina melts at above 2000°C. The molten bath has a temperature of only 950°C. This is the short-cut that makes aluminium easy to get.

Of course, it is "easy" in relative terms. We've seen the long way the source materials have to cover before they reach the aluminium-reduction cell. It also adds to the expense of aluminium production. Nor is the electrolytic process cheap to carry out. It takes 17.5 megawatt-hours of electric energy to make one ton of metallic aluminium.

This is much, but less than the 40 megawatt-hours used up by the early cells. Bigger cells, reduced heat losses and improved cell design have all served to more than halve the energy consumption. Undoubtedly, it will be reduced still more. By theory, as little as one-third of the energy actually used up would be enough to take pure aluminium out of the cryolite-alumina bath. The remaining two-thirds is wasted, partly with the heat dissipated by the cell into the atmosphere, partly due to the solution of the metallic aluminium on the bottom in the molten cryolite floating above it. And this waste can be cut down.

The major item of expenses in the manufacture of metallic aluminium is, however, the cost of alumina. Its preparation can be made cheaper both through improvements of existing processes and through fundamental departures. Today one ton of "silver from clay" costs as much as one kilogram of it a century ago. When its cost has dropped to one-tenth of its present-day figure, aluminium will oust iron and its alloys from all uses.

But to go back to making aluminium. The liquid metal collecting on the bottom must be drawn off and refined.

The liquid aluminium is taken out by means of either vacuum ladles or siphons. A cell operating on a current of about 50 kiloamperes will have a daily output of about 360 kilograms of aluminium. The metal is drawn off every two or three days.

The aluminium-filled ladle is at once placed under a hood. The hood has an opening through which a pipe is led in to admit chlorine gas from a cylinder. The gas is forced through the metal where it reacts with some of the aluminium to form aluminium chloride. The aluminium chloride vapours cause the non-metallic impurities to float to the surface. The hydrogen dissolved in the aluminium and some metallic impurities also succumb to the treatment. The impurities and the chlorides thus formed float to the surface as a grey loose powder which is removed by a perforated skimmer like the one housewives use in their kitchens.

After chlorination, as the treatment is called, the aluminium is taken to a remelting furnace. The remelting operation serves two purposes. Firstly, the metal further gets rid of non-metallic impurities and gases; secondly, the differences in composition between the different cell-withdrawals are eliminated, giving a large quantity of metal of one grade. Then the metal is cast either into pigs or bars for subsequent rolling. Pigs are cast in casting machines in which an endless chain of moulds moves past a pouring ladle or a remelting furnace. Bars in the Soviet Union are generally cast by

a semicontinuous method. This improves the crystalline structure of the metal.

That is how aluminium is made. It still carries about five parts of impurities in a thousand, mainly iron and silicon. Further refining is also carried out electrolytically. The purest grade of aluminium contains as little as two parts of impurities in a hundred thousand. Such metal has improved electrical conductivity, ductility and, what is especially important, very high resistance to corrosion. It goes to make high-quality folium, chemical and electrical apparatus, and protective coatings for other metals. Most often, however, aluminium is used in alloys with other metals.

ALUMINIUM IN ALLOYS

Aluminium did not become the metal of aviation overnight. At one time heavy steel was a successful rival to it. True, it was a long time, about thirty-five years, ago.

At that time newspapers carried photographs of the steel planes designed by the Russian aircraft designer A. Putilov. They were shown at international exhibitions and won high praise.

In effect, they were not heavier than those made of aluminium. But they were more durable, because they used stainless steel, while the aluminium alloys at the disposal of aircraft makers at that time would oxidize rapidly.

In the long run, however, steel failed in its competition with aluminium. Metal-makers found a way of improving the resistance of aluminium alloys to corrosion, and the planes made of them proved much cheaper than those from stainless steel.

The first commercial aluminium alloy was duralumin (from "dur", the French for "hard"), pioneered by A. Wilm and associates in Germany between 1903 and 1914. Wilm had been looking for additions which could improve the strength of aluminium. The best alloys were, in his opinion, those which carried five parts copper, one part manganese, and one part magnesium in a hundred. When annealed, specimens of this alloy had an ultimate tensile strength of up to 20 kilograms per square millimetre.

But that was not all that the new alloy could give. Wilm took several specimens of the alloy, heated them to about 600°C and quenched them in water. He was eager to learn whether this treatment would affect the aluminium alloy in the same way as steel. When he pulled a quenched specimen in a testing machine, the dial read an ultimate tensile strength of 25 kilograms per square millimetre. That was an improvement of twenty-five per cent. But Wilm was after alloys which could vie with steel in strength.

It so happened that the investigator was away from his laboratory for several days. The quenched specimens were lying on the table, collecting dust. Back to work, Wilm first of all turned to the bars to test them. After all, they had been made for exactly that purpose.

Something strange happened to the very first specimen; it was almost twice as strong as the bar tested a week ago. It burst under a load of about 38 kilograms per square millimetre. The second bar stood up to a load of 42 kilograms, and the third to 41 kilograms. There could be no mistake.

That was how a very interesting thing was discovered—the ageing of aluminium alloys after quenching.

Scientists have investigated the thing from all sides. Today we know that aluminium alloyed with copper, nickel, magnesium and some other metals keeps gaining in strength for several days after quenching. If it stands at ordinary (room) temperature, its hardness and tensile strength reach a maximum only five or six days after quenching.

But what actually takes place in the crystals of a quenched aluminium alloy? That has been a hard thing to learn. At high temperature aluminium dissolves more copper than at a low one. Therefore, when the alloy is heated, all the copper is dissolved in it. When the alloy is rapidly cooled, or quenched, the copper atoms have no time to detach themselves from the crystal lattice, and a supersaturated solid solution forms. It would be natural to think that ageing consists in the separation of the copper from the solution. But neither metallographic nor X-ray analysis could show this.

Finally, a far more complicated picture has emerged. Ageing only prepares the copper atoms for separation from the solution. While in a specimen just quenched, they occupy chance places, now they move to certain definite sites in the lattice, forming areas of increased copper concentration. As a result, heavy stresses are induced in the crystals, enhancing their strength.

The copper can, however, be thrown out of solution, if the quenched alloy is again heated to high temperature. The strength of the metal is then sharply reduced.

Today's designer has at his disposal a great variety of aluminium alloys. Some of them can stand up to a tensile load of 60 or 70 kilograms per square millimetre. This is a high strength, but all of these alloys fall an easy prey to corrosion. The point is that the alloys contain small grains of elements which can form local galvanic cells. So while pure aluminium lacks the strength of its alloy, its alloy lacks aluminium's resistance to oxidation.

One way to combine both properties is cladding. A block of duralumin is wrapped with a sheet of pure aluminium and is then rolled while hot. The duralumin makes a strong bond with the aluminium, and the composite sheet, known as Alclad, is produced.

Where a particularly high resistance to corrosion is required, Alclad sheet is thoroughly degreased, placed in a cell filled with strong sulphuric

acid, and made the anode of the cell. Current is turned on, and what is known as anodizing takes place. The treatment produces a hard corrosion-resistant film of oxide on the Alclad sheet about one-tenth of a millimetre thick.

If you look at the film through a microscope, you'll see a multitude of tiny pores reaching deep into the metal. If they are not to allow oxygen or water to attack the base metal, they should be filled up. This is usually done by dipping the metal in a solution of potassium-chromium compounds after anodizing.

Now the article is armed against both heavy loads and corrosion.

All that has been said about aluminium alloys applies to so-called wrought aluminium alloys. Immediately after quenching, they are very easy to work mechanically. And so they are rolled, forged, or cut. Only after they have been worked to shape do they become hard and strong.

There is also another class of cast aluminium alloys. They are very fluid when molten and will fill up all the crevices and recesses in the mould. On solidifying, they shrink very little, if at all. As a rule, cast aluminium alloys contain silicon, copper and magnesium.

Now that you've learned so much about aluminium, look at a high-speed plane standing on the runway with its wings swept back as if a swimmer ready to plunge into the water. The control tower gives a "go-ahead", its engines rev up, and the blades of the air-screws merge into transparent, glistening disks. The plane picks up speed until it takes off from the concrete. Now it is in the air, where it belongs. With a jerk, the landing gear doubles on itself and disappears in the wings. The speed and the altitude are increasing all the time.

What you can see in the air is in effect aluminium. For the wings and fuselage are made of Alclad sheets. The rivets (and there may be several hundred thousand in some planes) are also made of an aluminium alloy, very soft immediately after quenching and very hard on ageing. The landing gear, the cylinder blocks of the engines and a multitude of other engine parts are all made from cast aluminium alloys.

METALLIC FOAM

Foamed plastics are a very important group of polymers. They have remarkable properties. To begin with, they are very light in weight. You can easily lift a large block of foamed plastic single-handed. This is why foamed plastics are especially useful where it is important to keep weight to a minimum.

Foamed plastics are excellent thermal insulators because of the air in their pores. For the same reason they are efficient sound-proofing materials.

Unfortunately, foamed plastics suffer from a major drawback, low strength. A very promising way to overcome it is to make foamed metals. They would find a far wider use than foamed plastics.

Experiments with foamed metals are being carried out on a large scale. Newspapers have recently reported about foamed aluminium. It is made as follows.

Hydrides of zirconium, barium or lithium are dissolved in a bath of molten aluminium. The bath is then held for a few minutes at about 657°C. On decomposing, the hydride molecules give out hydrogen which fills the pores up to a few millimetres in diameter, forming throughout the metal. The metal rapidly swells. Hydrogen is very volatile, and its bubbles quickly float to the surface. So the aluminium must be cooled as quickly. This is done with a jet of cold water.

Foamed aluminium has a very low density, anywhere from 0.19 to 0.64 gram per cubic centimetre, depending on the composition and the conditions of manufacture. In other words, foamed aluminium floats on water like cork or balsa wood from which the famous raft *Kon Tiki* was made.

We can't yet say whether this firstling in the family of foamed metals, foamed aluminium, developed by a team of American scientists, is to become the very material about which both sci-fic writers and engineers dream. What is certain, however, is that we shall live to see foamed titanium, foamed steel, foamed beryllium and a great variety of foamed alloys.

Foamed metals have a bright future before them. But man knows very little about this division of metallurgy yet, especially about how to make such metals.

A RIVAL AND AN ALLY

As a metal of aviation and astronautics, aluminium has a very strong rival. It is one of the whole series of metals obtained for the first time by the British chemist Sir Humphrey Davy. It has a silver white colour across a freshly made cut; it melts at 651°C and boils at 1120°C; if raised to 550°C in open air, it ignites, burning with a dazzling flame. Its name is magnesium.

A good deal may be said about its properties. That in air it is quickly coated with a thin and dull film of oxide. That cold water does not practically attack it, while in hot water it replaces the hydrogen. That in an at-

mosphere of damp chlorine it ignites at room temperature and dissolves readily in diluted acids. All that is true. Yet the most important thing about magnesium is that it is the lightest structural metal. Its specific gravity is 1.738, and that of aluminium is 2.7. To put it another way, a plane built from magnesium alloys would weigh one-third less than when built from aluminium alloys of the same strength.

So magnesium may also be classed as a flying metal of today and to-morrow.

Magnesium is among the most abundant metals. It accounts for 2.3 per cent of the Earth's crust in weight and is found in about 200 out of the nearly 1,500 known and explored minerals. Sea water carries fourteen parts magnesium in ten thousand. Magnesium is a vital component of plants and animals. Some sea weeds contain as much as three parts magnesium in a hundred by weight, and sea sponges up to four parts. Magnesium is contained in chlorophyll and thus contributes to the all-important process that produces organic substances. Scientists have estimated that the chlorophyll of land plants alone contains about 100,000 million tons of magnesium. Lack of magnesium in soil causes severe diseases in plants, and its absence in food has the same effect on animals.

Magnesium is ubiquitous and its reserves are practically inexhaustible. Yet it remained almost unused for a long time. It was in the 1920's, or about thirty-five years ago, that it was used in alloys for the first time.

In 1937 magnesium production reached 20,000 tons, in 1940 the figure was above 35,000 tons, and in 1943 its output was in excess of 250,000 tons (leaving out the Soviet Union).

The bulk of the metallic magnesium goes to make alloys. Pure magnesium is no good as a structural metal; it is soft and weak. On the other hand, magnesium alloys are almost as strong as duralumin alloys.

Parts cast of magnesium alloys weigh one-fifth to one-third less than those of aluminium alloys, and half to three-fourths less than those made of cast iron or steel.

The most commonly used magnesium alloys contain eleven parts aluminium, four parts zinc, and two and a half parts manganese in a hundred. The aluminium and zinc of this community build up its strength, while the magnesium sharply increases its resistance to corrosion. Some magnesium alloys have additions of lithium, beryllium, calcium, cadmium, cerium, titanium and other elements. Some of these additions improve heat resistance, others increase ductility, still others reduce oxidability. Harmful impurities are iron, silicon, copper and nickel. They reduce mechanical strength and resistance to corrosion.

Like aluminium alloys, those based on magnesium are classed into two large groups of wrought and cast alloys. Use is most often made of cast magnesium alloys.

Work with magnesium alloys calls for special skills and precautions. When molten, they may ignite if brought in contact with air. So melting and casting are done under a blanket of slag. However, the wide-spread opinion that articles of magnesium alloys are inflammable and will catch fire for no reason at all is not true. What is true is that magnesium-alloy dust may explode in air. To avoid this, have your dust exhausts operating well when grinding or polishing magnesium-alloy parts. Chips of magnesium alloys are also a fire hazard. But solid parts made of a magnesium alloy can be ignited only by melting them. Not that it is easy to do. Magnesium alloys have a high thermal conductivity, and any spot heated locally will be cooled as fast as it heated.

Magnesium alloys offer the advantages of further reducing the weight and increasing the load-carrying capacity of planes, railway wagons and motor cars. This is why ever wider use is being made of magnesium alloys.

The search for ever better magnesium alloys is going on in many countries. The researchers are only at the threshold of important discoveries and findings. They have not yet come upon an alloy which would set an example to follow. They have not yet identified the alloying elements to use or the amounts in which they should be added. However, it will be found, a super-strong magnesium alloy against which corrosion will be almost powerless and which will be almost non-combustible. Simply it is waiting for its discoverer.

Though on a limited scale, magnesium is used in pure form. This use is in pyrotechnics, the manufacture of flares, tracer and incendiary shells and bombs. Pure magnesium is used as an alloying addition to cast iron improving its mechanical properties, and as a reducing agent in the manufacture of titanium and vanadium, which are hard to reduce. It removes sulphur from nickel and some alloys.

How is this metal produced?

AGAIN ELECTROLYSIS

Magnesium is never found native. The most important minerals used in magnesium manufacture are magnesite, dolomite, carnallite and bischofite. The Soviet Union has huge deposits of these magnesium minerals, magnesite in the middle Urals and the Orenburg Region, dolomite in the Donetsk area, the Moscow and Leningrad Regions, carnallite in the northern Urals, bischofite in the Crimean lakes, the Kara-Bogaz-Gol, and Lake

Elton. To this list we may add sea water, which is an inexhaustible source of magnesium.

Like aluminium, magnesium can be produced by electrolysis. Before the source material gets into the electrolytic cell, however, it is given, in addition to concentration, special treatments so as to change its chemical composition.

Bischofite, most often extracted from salt lakes, is given a two-stage dewatering treatment. The first stage is carried out in rotary kilns. This can, however, drive off only part of the water making up the crystals of bischofite. All water could be driven off by raising the temperature in the kiln, but then magnesium oxide would be produced, which is undesirable. Therefore the product is finally dewatered in another rotary kiln heated from the outside and filled with the chlorine gas.

The product thus obtained inevitably carries some magnesium oxide. To get rid of it, the material is melted in arc furnaces so as to slag off the undesired impurity. After settling, the pure magnesium chloride is tapped into a ladle with a tightly fitting lid and is sent for electrolysis.

Other magnesium minerals, differing in chemical analysis, are treated in some other way, no less complicated. In all cases, however, the end product is pure anhydrous magnesium chloride.

Magnesium chloride is perhaps more difficult to electrolyze than alumina. Magnesium is lighter in weight than the magnesium chloride from which it is obtained and it floats to the surface. At the same time, chlorine is given up at the other electrode of the cell. Because of this the cell must be kept closed at all times, which involves additional inconvenience.

Finally the operator moves a vacuum ladle to the cell and fills it with the liquid silvery metal. From the ladle it is then poured into moulds to form ingots. But this is still a crude metal. It must be refined.

Magnesium can be refined either by fusion with fluxes or by retorting. Retorting, as the name implies, is carried out in retorts, hermetically sealed steel cylinders. The ingots of crude magnesium are charged on the bottom of a retort, the lid is clamped, and the air is evacuated to a very high vacuum. Then the lower end of the retort is heated to 580-600°C, while the top end is cooled by outside air. The magnesium sublimes, that is, changes from a solid into a gaseous state without becoming liquid. The vapours rise to the top and settle there on the walls as bright clusters of crystals. Of course some of the impurities do the same, but those which sublime easier than magnesium settle at the topmost part of the retort, and those which are harder to vaporize settle in the lower part. So the magnesium is purest in the middle portion. The crystals from the middle portion, which account for about four-fifths of the original charge, are separated

from the rest, remelted and cast into the desired commercial form. The final product has only one part of impurities in ten thousand or even less. The purity may be further improved by repeated retorting.

That is how magnesium, the rival and ally of aluminium, is born. It is a rival because it is superior in some properties to the flying metal of today, aluminium. It is an ally, because, when added to aluminium, the two produce excellent structural alloys. Duralumin contains magnesium, and the best magnesium alloys have additions of aluminium.

Both, however, have to face still another and more formidable rival and contestant for the title "flying metal of the future" and especially "metal of interplanetary flight".

A PIECE OF ORE SET IN GOLD

The ore, or rather the mineral, is beryl, the exquisite beryl. It occurs as a multitude of gem stones—emeralds and chrysoberyls, aquamarines and euclases. Exquisitely faceted and set in precious metals, they adorned the crowns of emperors and the fingers of the rich. Yet, beryl is just a silicate of beryllium and aluminium, the sole source of beryllium metal.

Endless stories can be told about the pieces of beryl so highly valued by man for centuries. Much blood and sweat has been poured for these attractive but otherwise useless stones. Many lives have been lost and many underhand schemes have been devised because of them. However these are all bygone things about beryllium. Its future is altogether different.

The first man to run on beryllium was the French chemist Vauquelin who had spent years investigating gem stones. In his report to the French Academy about his discovery in 1798 he suggested the name "glucinium" from the Greek for sweet, as beryllium salts tasted sweet to him.

Beryllium metal was for the first time obtained in 1828. The tiny pinchful of dark-grey powder contaminated by impurities was not enough for the properties of the new metal to be established. It was not until 70 years later, at the turn of the 20th century, when beryllium was obtained in a relatively pure state by electrolysis, that investigations into its properties began.

The properties have proved truly remarkable. Probably only titanium can vie with beryllium in the happy combination of properties as useful to man.

Beryllium is a hard, steely-white metal closely akin to magnesium. It has a very low specific gravity (1.82) and melts at 1284°C, or at a temperature much higher than magnesium or aluminium does. This is a great advantage, because in the future planes will fly at hypersonic speeds and, as a result, in the face of intense heat. Yes, heat. The gentle breeze that

caresses your cheeks when you're walking turns into a springy mass when you're cycling. Its pressure builds up when you change to a motor car. And it becomes almost solid to your hand if you thrust it out of a plane flying at 200 to 250 kilometres an hour.

Do not try to stick your hand out of a supersonic plane, though. You will lose it. A flier who had to bail out of his plane unprotected was chopped up as if he had gone through a meat-grinder. The air scalped him and broke his legs, arms and ribs. The man had to stay in hospital for many months. He was lucky, because other fliers were killed in similar situations.

Striking at a plane at high velocity, air heats the plane's skin. This is why heat-shields have to be provided around the cockpit on high-speed aircraft. The heating is far more severe in the case of missiles and rockets. The V-2 missiles the Germans bombed London with towards the end of the second world war were at a cherry-red heat at the moment of impact because of the resistance of air. It is for this reason that so much emphasis is placed on high heat resistance and high melting point in the metals to be used in aircraft and spacecraft in the future.

Beryllium has all this and high strength at elevated temperature into the bargain. When heated to 400°C duralumin loses four-fifths of its strength, and beryllium only a half.

In terms of the strength-to-density ratio beryllium leads stainless and high-strength steels. For beryllium the ratio is 26, and for the two classes of steel the respective figures are 10 and 20. The framework of a multistorey building made from beryllium will be stronger than from the same weight of steel. A plane built of beryllium will have a range 40 per cent greater than an aluminium plane solely because of the reduction in weight. This is why beryllium has become a coveted metal to every aircraft and spacecraft designer.

Not that the interest in beryllium is limited to the aircraft industry. Well before aircraft designers came to think of it, beryllium was used for windows in X-ray tubes. This is because beryllium, hard and unmanageable, is highly transparent to X-rays.

Then metal-makers took interest in beryllium. They found that small additions of beryllium would markedly improve the properties of many metals and alloys. At one time car springs were made of plain carbon steel. After 800 to 850 thousand load cycles they would fail because of fatigue. Then a small amount of beryllium was added, and the steel came by a wide margin of strength. Now car springs can stand up to 14 million load cycles without so much as a sign of failure. This endurance has been imparted by beryllium.

Beryllium does not combine with magnesium. Yet an addition of as little as one part of beryllium in ten thousand makes magnesium alloys

highly resistant to oxidation both in air and in water. Even when heated to 700°C, such an alloy will not ignite. And again this fire resistance has come with beryllium.

Beryllium is a very efficient deoxidizer for steel. Neither aluminium nor magnesium can do the job better. Beryllium is the most important, however, as a component of what are called beryllium copper alloys. Its content is only two to two and a half per cent, but its effect is truly miraculous. Highly critical parts, such as springs, spring contacts, gears and bearings operating at high speed, pressure and temperature, are made of beryllium copper alloys. This is because after a suitable heat treatment they become as strong as the best grades of steel. They are very resilient and conduct both electricity and heat well. On top of all, they resist abrasion. Because beryllium copper never gives out sparks when it strikes a stone, it is made into picks, hammers and saws used in mines, gunpowder factories, and other jobs where fire hazard is present.

Beryllium copper ages almost in the same way as some aluminium alloys do. For ageing, beryllium copper is heated to 700-800°C, quenched in water and then held for several hours at 250 to 350°C. After quenching the metal becomes very ductile and as pliable as clay. The subsequent tempering turns it into a very durable and strong metal with a yield point of up to 128 kilograms per square millimetre, as against the 16 kilograms after quenching.

Still another important application for beryllium in metallurgy is the surface hardening of steel. The process is called beryllization and consists in that the steel to be hardened is placed in a container holding beryllium or its compound in powder form and heated to about 1000°C. The surface layer picks up beryllium and becomes very hard and resistant to oxidation at up to 800°C.

In addition to these important uses in metal-making, beryllium has attracted the attention of nuclear physicists. As it has turned out, beryllium can retard the neutrons passing through it without catching them, a very important property for a material used in nuclear reactors.

To cut the long story short, there is a great number of uses for beryllium in science and technology. Unfortunately beryllium is in fact a semi-precious metal. To quote the *New Scientist*, it costs about £20-£30 a pound for the raw (unworked) metal and from £50 to £500 a pound as components, compared with £200 a pound for gold. Beryl, its sole source, carries as little as about five per cent beryllium. Its abundance in the Earth's crust is as low as a few ten-thousandths of one per cent.

Is this to mean that beryllium, so attractive in its properties, is to remain the cluster of grapes from the fable about the Fox and the Grapes? Hardly so. After all, beryllium is twice as abundant in the Earth's crust as lead or cobalt.

The figures on its output seem to strike an optimistic note. In 1932 the Siemens Werke in Germany produced. two tons of this semi-precious metal. In 1937 the United States manufactured about seven tons of beryllium alloys. In 1959 the beryllium output (leaving out the socialist countries) was 180 tons.

Not that beryllium is free from shortcomings. It is very hard and will scratch glass at room temperature (just try and work it by cutting). While rather ductile when made very pure, it is very brittle and will go to pieces at a hammer's blow. This is why beryllium cannot be rolled, forged or drawn. Only if it is raised to a dark-red heat can it be forged, and then to a limited extent. In the manufacture of beryllium sheet, billets have to be rolled inside hermetically sealed steel containers at 300°C. So beryllium is a very difficult creature. But metal-makers know how to "break in" such "wild horses". One way is by using the techniques of powder metallurgy.

POWDER METALLURGY

Today it is a ramified and rapidly expanding industry. Although it handles only about one-thousandth of all the metals manufactured in the world, its position is very important.

This is because every kilogram of products made by techniques of powder metallurgy is the equivalent of several kilograms of components worked to shape by cutting. In powder metallurgy waste is almost non-existent, while in metal-cutting a huge amount of metal is turned to chips. Furthermore, one kilogram of cermets made by powder-metallurgy methods does the job of tens of kilograms of high-alloy tool steel.

Powder metallurgy comes in useful where all other methods fail to make a product of desired quality-from suitable materials.

How can, for example, the tiny filament of a lamp be made from super-hard tungsten which melts at 3400°C? Neither machining, nor drawing, nor rolling will do.

How can an alloy be prepared from two metals sharply differing in melting point, such as copper (which melts at 1083°C) and the same tungsten?

How can a material be obtained, consisting of a metallic and a nonmetallic component such as corundum or diamond dust?

How can a metal bearing bush be made so that it has an exact proportion of pores uniformly distributed throughout its bulk?

Powder metallurgy can do all of these jobs and a lot more. In terms of money and labour it vies successfully with other types of metal treat-
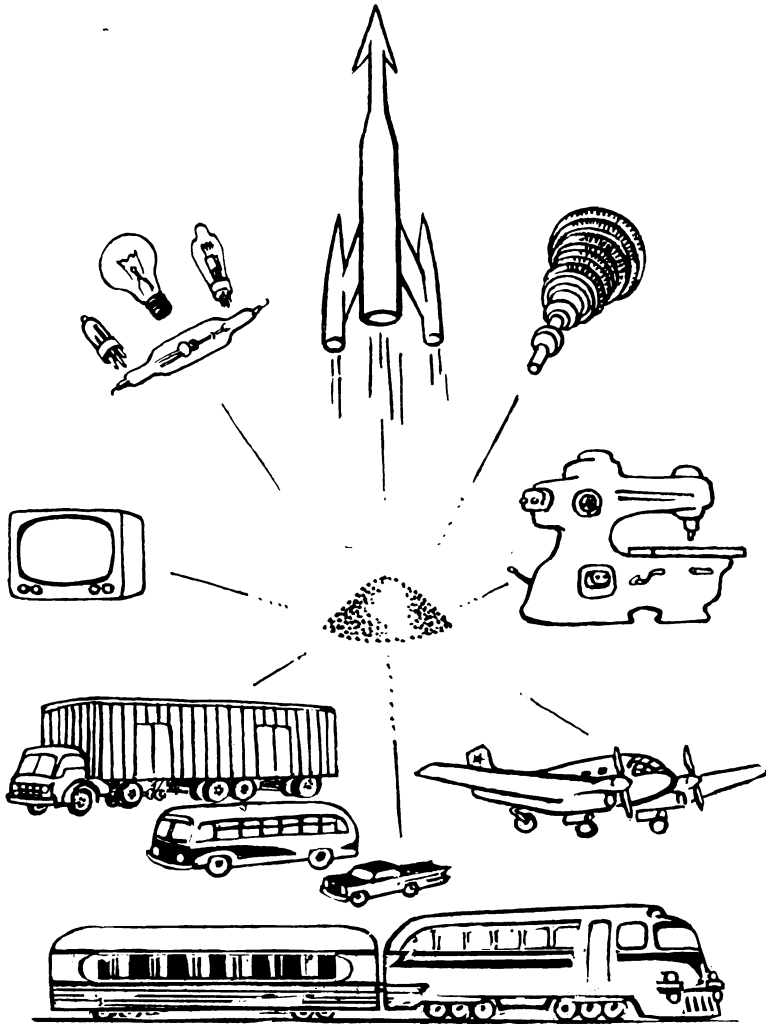
Here are only some uses of powder metallurgy

ment. It takes a skilled worker thirty hours' to cut a steel gear by the usual methods. Using techniques of powder metallurgy, a semi-skilled worker will do the job inside ten hours.

The dimensional accuracy and surface finish of components made by powder-metallurgy methods are so high that no additional working is required. It would be wrong, however, to think that powder metallurgy can replace all other methods. It suffers from a number of drawbacks. One of them is the high porosity of components because of which they are readily oxidized, and oxidation may occur throughout the bulk of the material. Also ductility is very low, and the dies in which metal powder is compressed to the required shapes are costly. The range of sizes and shapes is limited, so powder metallurgy is advantageous only where small components can be made on a large scale.

By far the most serious drawback of powder metallurgy, however, is the high cost of metal powders, its source materials.

Many methods have been tried, discarded and are being used for preparing metal powders. The simplest method is to crush brittle metals in ball-mills. The impacts of the steel balls turns the charge into small particles, the air blown into the mill carries away the fines, a separator grades the powder into the right size of particles and recycles the larger pieces for repeated grinding. Today powder-metallurgy engineers have devised a variety of ways for producing the right sizes and shapes of metal particles, so vital to the success of the subsequent operations. This does not mean, of course, that these are the best and most economical techniques. Most probably, the best methods are still awaiting their discovery.

Finally the metal powders are prepared. They are graded and mixed, which is also a delicate operation—the uniformity of the mixture is important to the quality of the product. Then the mixture is charged into steel dies and compressed to the required shape, making due allowance for shrinkage.

To understand what happens in the metal powder on compression, take a piece of metal. It is a solid body in which any particle is closely adjacent to its neighbours. This is not so in what are called colloids, in which tiny particles a few hundredths or even thousandths of a micron in size are dispersed in a liquid. The colloidal particles do not touch one another. Metal powders are in a state which is intermediate between the solid and the colloidal ones, because they come in contact with each other only over a fraction of their total area.

Pressing brings the particles closer to each other, and the area of contact increases. What is produced is called a compact. This is not a finished product yet. It must be sintered.

Sintering is done at a temperature well below the melting point of the main constituent of the mixture. But the temperature is high enough to bring about important physical changes, such as diffusion, absorption and solution. Upon cooling, the final product has the desired properties.

This is, of course, a very brief outline of the actual process. In each particular case some other steps or operations may be added. Sometimes hot pressing is employed and lower pressures are then allowable. Instead of steel dies, a liquid may be used to do the pressing. In some units the powders are rolled and not pressed. The compacts may be sintered in an inert atmosphere or in a vacuum.

Powder metallurgy is closely related to electrical engineering. Filaments and electrodes for lamps, X-ray tubes and electronic valves are all made from tungsten, molybdenum and tantalum by powder-metallurgy techniques.

The cermet tools developed in recent years have revolutionized machining by allowing a ten-fold increase in the speed of cutting. Hard-metal drilling bits have increased the rate of well sinking in mining. And again the success is due to powder metallurgy. Without it, it would be hardly possible to make cermet or hard-metal tools from high-melting (and brittle) carbides and some matrix metal. Thus titanium carbide, which is the usual component of cutting tools, melts at 3140°C, zirconium and niobium carbides at 3500°C, and tantalum carbide at 3380°C.

In addition to cutting tools, powder metallurgy produces punching and pressing tools, wire-drawing dies, thread gauges, and the like.

In all of these uses hard-metal products do their jobs well. A cermet die for making safety razor blades stands up to 2,000 million operations while an ordinary steel die has to be replaced after 15 million pressings. The service life of hard-metal rolling rolls is 100 times greater than that of plain steel rolls. Before it is completely worn, a steel wire-drawing die will make 80 kilograms of iron wire, and one from a sintered carbide will fail only after as much as 50 tons of wire has been drawn, or 600 times more.

Such are the hard metals produced by powder-metallurgy techniques. They could be called high-speed materials, because their uses are often related to high speed. And increased speed is a distinctive feature of present-day technology.

Take the jet engine, the backbone of modern aviation, as an example. Its advent almost doubled the speed of planes. With it, planes can climb

where the piston engine cannot work. However the jet engine is not allowed to develop its full power. More air than is necessary is admitted into its combustion chamber and water is sometimes added for the sole purpose of reducing the temperature of the combustion products, although the higher their temperature, the more economical is the engine. The explanation is simple. Materials are not yet available which would bear the full brunt of gases as hot as 1500 to 2000°C.

Existing cast alloys containing additions of chromium, nickel or cobalt fail at temperatures over 850-900°C. Above this temperature is the realm of refractory metals, their carbides and nitrides, which can be made into the desired components by powder metallurgy.

One of the most promising materials is titanium carbide. It stands up well to thermal impact, rapid heating when the engine is being started up, and rapid cooling after the engine has been cut off. With an addition of 20 per cent cobalt, it is twice as strong at about 900°C as the best heat-resistant steels.

A good deal of ingenuity is put into ways and means of reducing the temperature of the jet-engine propelling nozzle. One such technique is sweat or transpiration cooling. The coolant (usually the fuel) is injected through the pores of the porous wall material of the jet pipe. It transpires to the surface to sweat there, bringing down the temperature of the pipe. And again the porous material is made by powder metallurgy processes.

Similar processes are used to make oilless or self-lubricating bearings. They are made by compressing powdered metals and graphite at high pressure and sintering the compact. After finishing, the metal is impregnated with a lubricant. As a rule, it can absorb about 35 per cent of its volume of lubricant. When in service the bearing becomes hot, the oil expands and transpires to the surface, producing a lubricating film on it. On cooling, the material again absorbs the oil like a sponge.

Powder metallurgy makes fine filters and clutch linings, gears and cams, washers and magnet cores, motor brushes and relay contacts, and multitudes of other things which can hardly be listed here. And tomorrow the list will be longer.

This brings us back to beryllium, for components from beryllium are made by techniques of powder metallurgy.

The pyramids where the ancient Egyptians buried their pharaohs were marauded long ago. The same fate fell to the rock tombs of their kings. The only burial which has remained intact is that of Tutankhamen, an Egyptian king who lived in the 14th century B.C.

When in 1922 his tomb at Karnak was excavated, the archaeologists found remarkable treasures there. Apparently Tutankhamen was very fond

of the arts, for his tomb was packed with masterpieces. Among them were daggers decorated with powdered gold. This is the earliest authentic application of powder metallurgy.

Powder metallurgy was also known to the Incas, the ancient race of Peru, who knew how to make jewelry by sintering powders of the precious metals. After their fall this art remained forgotten for centuries. Metallurgy took another road of development.

In the early 19th century the art of powder metallurgy was resurrected for a short time for making articles from refractory metals. This was done by Pyotr Sobolevsky, an outstanding Russian metallurgist. He used powder metallurgy techniques for making coins and medals from platinum. The metal could not be melted at that time, for there was no way known for obtaining a temperature of 1773°C, the melting point of platinum. Sobolevsky used the platinum sponge obtained by a chemical treatment of naturally occurring minerals, compressed it in dies, heated the compact, and again compressed the material to the requisite shape. The articles were dense and strong. This happened in 1826.

His process remained in use both in Russia and abroad for several decades. Then metallurgists learned how to melt platinum, and powder metallurgy was again dropped for many decades to come.

It made a come-back at the turn of the 20th century and seems to have come to stay with us. The chances are it will be steadily gaining more and more ground.

ARE THERE OTHER WAYS?

It is no easy job to make beryllium metal. As in the manufacture of aluminium, the first step is to prepare pure beryllium oxide.

Of course, no one uses the gem-stone varieties of beryllium-bearing minerals. The source is commercial beryl occurring as colourless or greyish crystals in many places all over the world.

The preparation of pure beryllium oxide involves the fusion of beryl ore with lime in arc furnaces, pelletizing, sulphatization, leaching of the beryllium sulphate, thickening of the liquor by evaporation, precipitation, centrifugal separation, crystallization and drying. This long chain of operations produces fairly pure beryllium oxide. Now the oxide is converted to beryllium chloride in a suitable furnace. This compound is drawn off from the furnace as a gas which is then made to condense. The condensate goes to the electrolysis department.

Since the electrolysis is carried out at as low as 350°C, beryllium metal is evolved in the form of solid flakes. They are collected, dried and pressed

into compacts. The compacts are fused to metal form in a hydrogen atmosphere at a temperature of 1400°C. The final operation of remelting and pouring into moulds is carried out in a vacuum electric furnace. The molten metal is cast into rods. They contain not more than two parts of impurities in a thousand, mainly beryllium oxide.

In order to make a window for an X-ray tube, a slice 2.5 to 3 mm thick is cut off from such a rod with a carborundum disk. The only thing left to do is to polish the beryllium blank.

There is also another, thermal, method for making beryllium metal. But it is in no way simpler and easier than the one just described, although it is used more often.

One way or another, it takes much ingenuity to manufacture the flying metals aluminium, magnesium and beryllium. Aren't there any other, more direct methods, such as are used for making iron, so that all impurities could be slagged off at once, leaving pure metal behind?

The search for such methods has been under way for a long time now in all countries making the three metals, and the researchers already have something to show for their effort.

One such method has been developed for the production of magnesium from its oxide. The oxide is reduced to metal form in electric furnaces by the carbon of petroleum coke. Magnesium metal escapes from the furnace as a gas at 1950 to 2050°C. The gas is condensed and collected as dust in bag-filters. In another reduction process the magnesium is replaced in magnesia by aluminium metal.

The situation is far more complex in the reduction of aluminium or beryllium. Because of their great affinity for carbon the two metals form carbides. Therefore, a second metal has to be used so as to dissolve the reduced metal and protect it from contact with carbon. That is how copper-beryllium and nickel-beryllium alloys are made, with copper and nickel serving as the solvents for the beryllium.

By about the same method silico-aluminium, an alloy of silicon and aluminium, is prepared in arc furnaces. The silico-aluminium may then be treated so as to obtain pure aluminium.

Will these little-used processes become everyday practice for the flying metals? Hardly so. In all probability, further progress will be sought in the well-investigated electrolytic methods. Yet, you can never tell. The history of science is full of sharp and unexpected turns in the development of whole industries. We may live to see the discovery of very simple and cheap ways of producing these metals. After all, the ancient Roman metallurgists made aluminium from clay without any idea about electricity. Even though it's only a tale, it may give inspiration.

Lithium is the lightest of all metals. With a specific gravity of 0.534, it is half as heavy as water and one-fifteenth as iron. It would be not a bad idea to build planes and spacecraft from such a metal!

Unfortunately, its other properties seem to have conspired to make it an unattainable goal to designers. As to mechanical properties, lithium looks like lead; it is as soft and undurable. You can hardly build wings for supersonic planes from such a pliable and weak metal.

Lithium melts at 186°C and boils at 1336°C. In open air it will ignite if heated to about 600°C. It is hardly enviable to be in the capsule of a spaceship built of lithium. A burning match dropped by accident will melt out a gaping hole in it. Just imagine what the inevitable drag will do to the craft!

Lithium readily combines with atmospheric nitrogen and oxygen at room temperature. If you leave a piece of lithium in a glass jar with a well-ground stopper, you'll hardly be able to open it later. The lithium will have absorbed all the air in the jar, building up a vacuum, and the outside pressure will lock the stopper. A flying machine made of lithium would not be able to wait for its passengers to come aboard; it would turn to a brownish powder, a compound of lithium, nitrogen and oxygen. The crew of a lithium spaceship would find themselves in a very unpleasant situation. The atmosphere of many planets contains much hydrogen, and lithium has a greater affinity for hydrogen than for oxygen or nitrogen.

This property is not completely useless or harmful. In some applications a small amount of lithium can be used to fix large volumes of hydrogen. One kilogram of lithium hydrate (as the compound of lithium and hydrogen is called) can be easily packed in a box for macaroni, and it holds 1,500 litres of hydrogen! In some cases it is more convenient to carry hydrogen as a lithium compound than in heavy steel cylinders, and it may be added that today this is one of the most important applications for lithium. Its other uses also involve its compounds and alloys.

Lithium hydrate is an excellent deoxidizer for molten metals. Lithium hydroxide is used in alkaline batteries to extend their service life. Lithium-base greases, which do not grow thick below zero or too fluid at elevated temperature, are used in aircraft engines. Lithium salts are added to special grades of glass to make them transparent to ultra-violet rays. The screen of your TV receiver also contains some lithium. Still, lithium is awaiting its widespread use.

You should not be discouraged by the fact that pure lithium is weak, highly active chemically, and melts at a low temperature. Aluminium, too, is not strong or stable when it leaves the electrolytic cell. But man makes it strong and stable, tailoring it to his needs. He will be able to tame lithi-

um as well. He has already made a number of lithium alloys of fairly good quality. Thus aluminium alloyed with twenty parts lithium in a hundred melts at 720°C. That's not bad at all! Zinc alloyed with eighteen parts lithium in a hundred melts at 520°C.

It is very likely that man will learn how to make lithium stronger and more resistant to corrosion without spoiling its valuable lightness. Then lithium will be a truly flying metal, attractive to spacecraft designers and capable of carrying man to other planets.

FUEL FOR SPACESHIPS

Any space system today is mainly a cluster of tanks holding fuel and oxidant. The payload, which is the crew capsule in manned spacecraft and the instrument container in unmanned probes, takes up very little space. Why is it so?

This is because very much energy has to be spent to break the chains of the Earth's pull of gravity. This energy is supplied by the fuel in the tanks. Chemical fuels, however, generate relatively little energy per unit weight. Therefore large quantities of fuel have to be provided on board a spaceship or probe.

Konstantin Tsiolkovsky, the first man to blaze the trail into outer space in his books and projects, suggested the use of a mixture of oxygen and hydrogen. On complete combustion, every kilogram of this mixture generates over 3,000 large calories of heat. This looks "big" indeed. For a mixture of kerosene and oxygen gives up only 2,200 calories, and every kilogram of nitroglycerine, one of the strongest explosives known to man, generates only 1,480 calories.

Despite this advantage, however, a rocket burning the oxygen-hydrogen mixture would be prohibitively large and cumbersome and made in several stages. No, the way out lies in better fuels.

It appears very attractive to utilize nuclear power for rocket propulsion, and research is under way in many countries. However, the difficulties are both many and formidable. No one can say yet how they will be overcome, if at all.

Meanwhile an interesting approach was suggested by Friedrich Zander of the Soviet Union as early as the 1920's. His plan was to use some metals as fuel.

What metals? Those which give out much heat on burning, among them the "flying metals". Ranking first among them is beryllium, which generates 15,050 large calories per kilogram when it combines with oxygen. It is followed by lithium with 10,270 large calories, and finally aluminium with 7,041 large calories.

So it may well happen that beryllium and lithium alloys will go to make the wings of planes and the hulls of spaceships while the same metals in pure form will burn in their engines. It is also very likely that these metals will hold out a helping hand to man in his conquest of the Universe.

SEARCH FOR OTHER CONTESTANTS

Can't there be any more contestants among the metals that aspire to be called "flying"?

Let's have a look at the elements concentrated in the left-hand part of the Periodic Table. One of them is sodium, adjacent to lithium. It was discovered by Sir Humphrey Davy in 1807.

Sodium is very abundant in the Earth's crust, accounting for about 2.64 per cent by weight. Huge amounts of sodium are dissolved in sea water. Common salt is a compound of sodium and chlorine. So, it is not a rare metal, and can be produced in any practical quantities.

Sodium is a soft, silvery-white metal. It can be cut with a knife like cheese and melted on the lid of a tea-kettle, for its melting point is 98°C. It boils at 883°C, with the evolution of purple vapours.

Those are all properties not befitting a flying metal, which should be able to withstand both high statical stresses, and sudden impacts and great vibration, and, of course, should better resist high temperatures. On the other hand sodium is a very light metal—its specific gravity is only 0.97 and it floats on water. This is an obvious advantage for a flying metal.

Sodium shows extreme reactivity. In open air it becomes oxidized at once. This is why it is stored immersed in kerosene. It violently reacts with water, combines directly with sulphur, iodine and chlorine. This makes us discount sodium as a flying metal. It is very unlikely that any one will think of making wings for ion-propelled craft from a metal which is only too eager to combine with some other element.

But, again, you can never tell. It may so happen that some time in the future an alloying addition will be found capable of imparting heat resistance and chemical stability to sodium, or a heat treatment will be developed, improving its properties as a structural metal. For the time being, sodium is doing what it can.

A total of about 50,000 tons of sodium is produced all over the world every year. Some of this output is used in metallurgy, because sodium is an efficient reducing agent in the manufacture of such metals as zirconium. The chemical industry also uses it in the manufacture of, say, synthetic

rubber. Much sodium is processed into its compounds sodium cyanide, sodium peroxide, and the like.

Still another metal which might be made "flying" is potassium.

Potassium is also very abundant, accounting for 2 per cent of the Earth's crust by weight. It is present in many rocks, is dissolved in sea water, and contained in living organisms. The huge algae macrocystis contain up to three per cent of potassium. Academician Fersman aptly called it "the basis of vegetable life".

The first man to describe its properties was the same Sir Humphrey Davy who obtained potassium metal in 1807. Potassium is very soft, softer than sodium. With a specific gravity of 0.86, it is lighter than sodium, which would seem to be an advantage. But it melts also at a lower temperature, 62°C, and boils at 760°C. Chemically, potassium is a twin of sodium. That is why chemists could not unmistakably tell potassium compounds from sodium compounds until the mid-18th century. The two metals only differ in the colour of their vapours as they boil. Those of potassium are bluish-green.

Potassium is still more active than sodium. It oxidizes readily in a damp atmosphere, eagerly absorbing the moisture. It violently reacts with water, with the evolution of hydrogen. Drop a grain of potassium into a plate filled with water; the grain will run all over the surface with a hissing sound. In a moment a bright flame will be seen above the grain. It is the burning of the hydrogen given up by the water. Potassium combines literally with all non-metals.

From this review of its properties it is clear that potassium will hardly ever become a flying metal. But it is unsurpassed as a constituent of fertilizers. In the Soviet Union about ninety per cent of its production is used up as fertilizers. Another use for potassium is in the form of its liquid alloy with sodium as a coolant or a heat-transfer medium. Its radioactive isotope which has, as geochemists believe, played an important part in the Earth's evolution, may also find some use.

If we go one square down just below potassium in the Periodic Table, we'll find ourselves in the place occupied by rubidium.

Rubidium was discovered by Kirchhoff and Bunsen in 1861, by the then new method of spectral analysis. The name "rubidium" owes its origin to the dark-red lines the scientists noticed in the emission spectrum of the metal.

Rubidium is less abundant than sodium or potassium, accounting only for 0.03 per cent of the Earth's crust by weight. This is not a reason,

however, for rejecting it. Many metals widely used in engineering are scarc
er than that. But it is no good as a flying metal. With a specific gravity
of 1.5, rubidium is heavier than sodium or potassium. It is softer than
either of the two and melts at as low as 39°C.

Rubidium is unique in terms of chemical activity. It ignites at once
upon contact with air and burns completely. It decomposes water so vio-
lently that you may think it exploded. Even cooled to 108°C, rubidium re-
places hydrogen in ice. At 300°C, rubidium vapours destroy glass, ousting
the silicon from it. There is probably not a single non-metal with which
rubidium would not react at once.

Rubidium is obtained in a vacuum and stored in kerosene. It has al-
most no practical uses.

Now let's look at one more metal from the same Group I of the Peri-
odic Table. It is cesium; it is located just below rubidium.

Cesium was discovered by the same German scientists Kirchhoff and
Bunsen with the spectroscope. Its name means "blue", by the colour of
the lines in the emission spectrum.

Cesium is the heaviest of the three alkali metals we've discussed; its
specific gravity is 1.9. The low melting point of 28.5°C makes cesium one
of the three metals (with mercury and gallium) that are liquid at room
temperature. You would be able to melt it with the heat of your palm,
but never do this. For it ignites in open air at once. It also ignites in an
atmosphere of chlorine or on contact with fluorine. It reacts vigorously with
sulphur, phosphorus and water. At 300°C it destroys glass and quartz, oust-
ing the silicon from them.

Man has learned how to utilize the high chemical activity of cesium. If
you place a tiny speck of cesium in a vacuum valve, this will be a vacuum all
right. For the cesium will absorb what air has been left in the valve envelope
after evacuation. For stability, cesium is alloyed with calcium and barium.

Although of limited industrial value, cesium has a very important
and unique application, the origin of which is traceable to the discovery
made by the famous Russian physicist Stoletov in 1888.

On February 26, that year, working in his laboratory at Moscow Uni-
versity, he connected the negative side of a galvanic battery to a zinc disk
and the positive side to a metal mesh placed opposite the disk. The circuit
was opened, and no current was flowing around it; the galvanometer placed
in the circuit indicated zero.

Now Stoletov illuminated the zinc disk with a strong beam of light,
and the galvanometer deflected at once, indicating the flow of an electric
current around the circuit. As the intensity of illumination increased, the
galvanometer deflected more and more. When he turned off the light, the

galvanometer limply dropped to zero, because there was no current flowing in the circuit. It appeared that light had completed the circuit.

The phenomenon thus discovered was named the photo-emissive effect, and the device Stoletov used in his experiments may well be called the ever first photo-electric cell.

What, in a nut-shell, is the photo-emissive effect?

Light, when it falls on some elements, knocks out from their surface electrons, those carriers of elementary electric charge. If made to flow in orderly manner, these electrons constitute a photo-electric current.

One of the elements capable of emitting electrons under the action of light is zinc. In Stoletov's experiment the electrons knocked out of the zinc disk were attracted by the positively charged metal mesh, thereby completing the circuit and giving rise to a current around it.

Very few metals can emit electrons under the influence of light, and zinc is far from being among the best performers in this respect. For a metal to be capable of shedding its electrons readily, it must have a special lattice.

Exactly such a structure is found in the alkali metals. Their outer shell has only one electron, very remote from the nucleus. This distance is especially great in the element cesium. This is why cesium readily parts with its outer electron and is the best performer in the photo-emissive act.

It is not easy, however, to put cesium to work, because it melts at room temperature. As a way out either some cesium is deposited on a support of silver oxide or photo-electric cells are made of an alloy of cesium and antimony.

Today photo-electric cells are quite at home in many divisions of technology. These "magic eyes" read the sound tracks of motion-pictures, and operate in facsimile transmitters which faithfully convert drawings, pictures or signatures into suitable electric signals so that these can be as faithfully received at distances of thousands of kilometres and changed back to the respective image. Photo-cells help to transmit images of moving objects from TV studios to the screens of the TV receivers at our homes. Photo-cells work diligently in very many automatic control systems, especially where watch must be kept on changes in colour, illumination, transparency or brightness. They also keep watch on the position of objects and count the products coming off assembly lines.

In nearly all of these devices, increasing in number all the time, the job is done by cesium. So it has become quite a big thing! It has risen to prominence in a vital field—process automation.

Still, it will probably never become a flying metal. It is no rival to aluminium, magnesium or beryllium. It is their companion, rather. It will travel into outer space in the automatic instruments, and not as the hull, of spacecraft.

Or, perhaps, we can find prospective "flying" metals in Group II of the Periodic Table, next to magnesium, the acknowledged flying metal. Entered right below it are three alkaline-earth metals, calcium, strontium and barium. The three were first prepared in metallic form in 1808.

Calcium is the closest neighbour of magnesium. It is a very common element, accounting for 3.6 per cent of the Earth's crust by weight. It is very important in organic life. Very few organisms, such as some of the simplest fungi, can exist without it. There are organisms which hoard it. Certain species of algae and molluscs carry as much as thirty-eight parts calcium in a hundred. In man calcium accounts for fourteen parts in a thousand and is concentrated mainly in the bones.

Calcium never occurs native. Its natural compounds, however, are known to any one. These are marble, limestone, gypsum, and the shells of sea and river snails.

Calcium is made by the electrolysis of fused calcium chloride, or by thermal processes under high vacuum from lime reduced with aluminium. It is a silvery-white metal of specific gravity 1.55. It melts at 851°C and boils at 1439°C. It is so soft that it can be cut with a knife. It is also very active chemically. It tarnishes rapidly in air with the formation of a bluish-grey film of oxide which protects it from further attack. It violently reacts with water and acids, liberating hydrogen. It is stored in kerosene.

Of course calcium metal is no good as a structural material. But it has quite a number of important applications, such as in bearing metals of the lead-calcium or lead-barium-calcium type; as a reducing agent for beryllium; as an alloying agent and a deoxidizer for copper; and in a host of other cases. Its compounds also play an important part as building materials, each of which would take up a volume to describe.

The next square in this row is occupied by strontium. It is not so common as calcium. Strontium was named after Strontian, a town in Scotland. The chief minerals are celestite and strontianite. From these substances all the other compounds of strontium are prepared.

Of specific gravity about 2.6, it is heavier than calcium. It is more ductile and can be forged. It melts at 752°C and boils at 1366°C. In air it tarnishes rapidly with the formation of a yellowish film of oxide. It decomposes water still more violently than calcium.

Strontium gives a brilliant crimson colour to a gas flame. Railway flares, signal shells and fireworks contain various amounts of strontium salts. Its other applications include some drugs, paints and lubricating greases of high stability.

Barium, found just below strontium in the Periodic Table, is heavier than its top-floor neighbours, being of specific gravity 3.5. A metal as heavy as that must possess very good structural properties if it is to be used in the "flying" occupation. Unfortunately, barium does not.

It is a soft, white metal which tarnishes in air in no time. It reacts with oxygen, water, nitrogen and hydrogen. Like all other "wild" metals, it is stored immersed in kerosene.

Barium metal has almost no uses, except in bearing metals of the lead-barium-calcium type.

Mention should be made of one of the uses to which barium sulphate is put in medicine. Mixed with porridge, it is fed to patients who want their intestines to be X-rayed. Against its background, X-rays produce a clear image of the stomach and intestines.

The chances are astronauts in the future will take along calcium, strontium and barium. Calcium might be used in the artificial soil of the green-houses which will supply vegetables to the crew. Strontium might be used in signal flares or in fireworks with which to celebrate the happy ending of a long journey. Barium compounds might be used in their first-aid kit. None of the three, however, has any chance of becoming a flying metal.

Is this to say that aluminium, magnesium, beryllium and lithium have no rivals in the Periodic Table? No, this is not so. For the Periodic Table has a metal in Group IV which may well oust them all in that capacity. Its name is titanium. We shall discuss it later on.

7

COPPER
AND ITS NEIGHBOURS
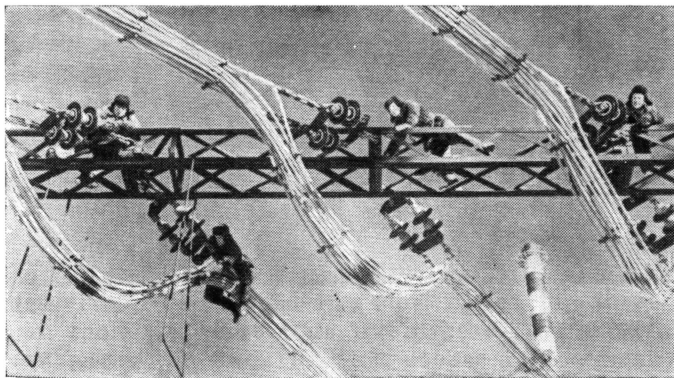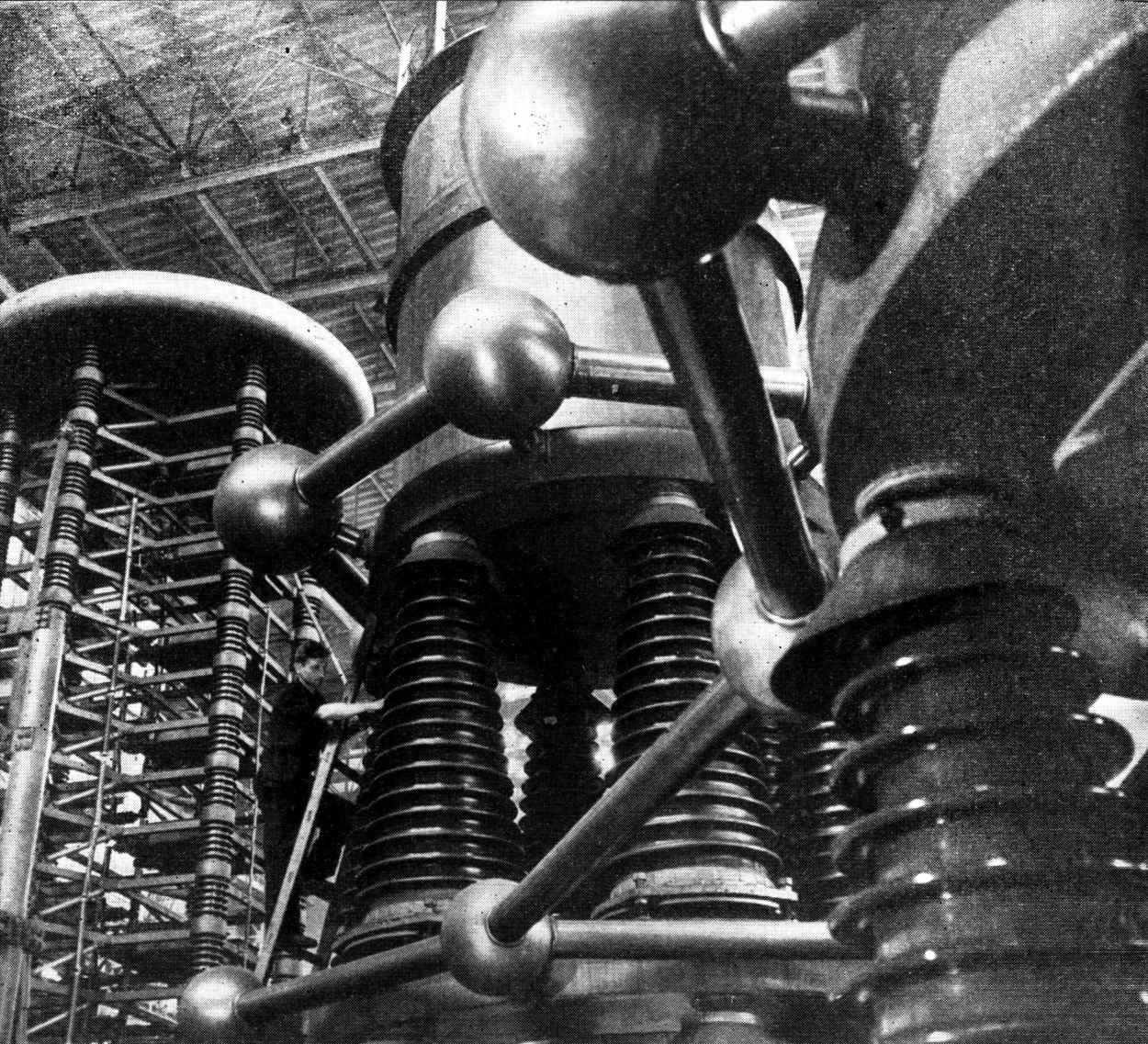
Man made the acquaintance of copper at the dawn of his history. He may have been attracted by the spongy lumps of this red metal covered by a brilliantly green film of oxide. But prehistoric smiths could hardly give copper its due—to them it was too soft and weak.

The metal became useful to man after it had combined with tin to make bronze. This ringing word has given the name to a whole period in human history. The bronze sword crowded out the stone axe, and the bronze plough ousted the wooden hoe. For many centuries bronze remained the best material for cannon and bells, utensils and tools.

Then the iron age came, but copper remained. The two metals each did its own job in man's service. As the production of iron and steel grew, that of copper also expanded. True, it expanded at a slower pace, but that was because the richest and, therefore, most attractive deposits of copper ores had been depleted a long, long way back. In fact, copper had become more costly to make than iron.

The situation changed when man had tamed electricity and discovered that copper has a very valuable property, high electrical conductivity. Iron cannot compete with it as a conductor material. And copper, the very pure copper ignored by the ancients and alloyed with tin by the artisans

of the bronze age, has become the basic metal of electrical engineering. So copper has been given a second lease of life.

Today copper goes to make conductors for power transmission lines, those channels for streams of electricity, the electric motors of machines, and the wiring of radio and TV sets.

"Communism is Soviet power plus electrification" said the great Lenin. The Soviet people have made these words their motto. They launched the GOELRO plan which laid the groundwork for the country's electrification. Since then they have built the Dnieper Hydro on the river Dnieper, the Lenin Hydro on the river Volga, the mammoth Bratsk Hydro on the river Angara, and a great number of large thermal power plants.

To build them, the country needed much copper. So copper smelteries were built at Krasnouralsk and Karsakpai in Kazakhstan under the first five-year plan, near Lake Balkhash in Kazakhstan, at Revda in the central Urals, and at Mednogorsk in the southern Urals under the third five-year plan.

COPPER—WHAT IS IT LIKE?

Copper is the only metal other than gold that has a natural colour. When pure, copper appears salmon-pink. It is tough and malleable. Of specific gravity 8.95, it is heavier than iron but it melts at as low as 1083°C and boils at 2360°C.

However, its physical properties have very little to do with its widespread use today. Copper is valued mostly for its high electrical and thermal conductivity. Only silver is a better conductor of both electricity and heat. The two metals lead all others in this respect. Iron offers five times as great a resistance to the flow of electric current, aluminium one and a half, zinc three, tungsten twelve, and titanium thirty-five times as copper does. The proportion is about the same for their heat conductivities.

Why is it then that copper has not become a metal of heat engineering? Why is it that no one builds copper boilers, copper radiators or copper heat exchangers?

There are several reasons for this. Firstly, copper is not strong enough. Secondly, it is too costly to be cast into heating radiators. Thirdly, there is not much to be gained by using copper where cast iron or steel will do. This is because heat transfer through the wall of a heating radiator depends not so much on thermal conductivity, which *is* great in the case of copper, but on the transfer of heat first from the water to the metal and then from the metal to the surrounding air. All in all, copper has not proved attractive in this capacity.

Ancient metal-makers were better off than their present-day successors. They had at their disposal the untapped treasures of the planet. They were able to use what was lying literally on the surface. All of the subsequent generations have had to be content with what was left after them.

On the other hand, the ancient craftsmen lacked the knowledge and skills of the present-day metallurgists. Although we have to use much leaner ores than our ancestors did, we have much more to show for it. A very convincing example is provided by copper, the most ancient of all metals produced on a large scale.

Of course, metallurgists have always sought the richer ores of the metal. In all probability the ore mined in Cyprus, the island which has given the Latin name "cuprum" to copper, carried at least twenty-five parts copper in a hundred. The ore deposits worked in Spain as early as 100 B.C. were apparently as good. Gradually the ores grew leaner and leaner, yet a century ago it was thought economical to mine only ores containing at least ten to fifteen parts copper in a hundred. Today such ores may be encountered in the Congo, where they were found much later than elsewhere. Ordinary commercial ores usually contain two or three per cent copper.

Copper smelters, however, regard them as sufficiently attractive to process. In fact, it pays to extract copper from ores containing as little as five or six parts of this metal in a thousand. This is because cheaper methods of extraction are continually developed which show a profit in recovery of copper from ores too lean to be treated by previous methods.

Until the turn of the present century the basic process for the extraction of copper had been the direct smelting of copper ores, called the pyrometallurgical method. When a charge of ore is molten, the bath separates into two immiscible layers, one being what is termed the matte, and the other the slag into which most of the gangue goes.

It is hardly worthwhile using this method to treat ores carrying five parts copper in a thousand. For one thing, nearly all the fuel would go to melt the gangue. For another, so little copper would be obtained that all of it would dissolve in the slag.

Precisely for this reason the pyrometallurgical method is now applied only to the richer ores and to the ore grades containing sulphur. Such ores are smelted with reduced amounts of coke and yield also sulphuric acid or sulphur as a by-product.

Before smelting, sulphide copper ores are beneficiated. This treatment separates the gangue and the accessory ores to give a copper concentrate. Then the concentrate is smelted to a matte.

Oxidized copper ores, or ores carrying copper-oxygen compounds, are treated by the hydrometallurgical method, or leaching. The copper of the

ore charge passes into solution, and the gangue is left as a solid residue. The copper is precipitated from the solution in an electrolytic cell.

Of the three methods described, use is most often made of beneficiation and concentrate smelting. This method accounts for three-fourths of the copper produced in the Soviet Union and at least four-fifths in the world.

Very often copper ores also contain the ores of other metals. For this reason resort is made to selective flotation, which yields additional concentrates of zinc, cobalt, molybdenum, and so on.

Such are the methods that have made the leaner ores quite profitable to process. Now an ore can be stripped of its copper content without any fuel burnt to melt the gangue. Man has now learned to extract more copper from the leaner ores than he did from the rich ones in the past. Also he knows how to extract other metals from these ores.

Now let us see what happens to the copper concentrate after it has arrived at the copper smeltery from the ore dressing factory.

First of all the concentrate high in sulphur is roasted. Roasting is done in multiple-hearth roasters, round towers about ten metres tall. A roaster has a central hollow shaft carrying arms and rabbles which turn over and advance the concentrate across the hearths in succession and towards the circular hole made in each. Thus rabbled, the concentrate passes through all of the furnace to be discharged at the bottom.

In a roaster the concentrate goes down and the combustion gases come up. The exhaust gases carry about seven per cent sulphur trioxide, a very valuable source material for the manufacture of sulphuric acid.

Sometimes fluxes are added to the charge of copper concentrate, and two to four kilograms of pulverized coal. As a rule, however, some fuel is only needed to start up the roaster. Once it is ignited, the process is sustained by the heat given out by the burning of the sulphur. The temperature inside the roaster may be as high as 750-800°C.

Although roasters can still be seen at many smelteries, their days seem to be numbered. For a far more efficient method has been found for treating the copper concentrate. The method is known as fluidized-bed roasting.

A FLUIDIZED BED

Chemical reactions between liquids proceed with amazing smoothness. What you have to do is only to pour the reagents together and shake them for stirring. In gases the rate of reactions is still greater. This is because both liquids and gases are in intimate contact over a vast area. If the react-

ing liquids do not dissolve each other, you can produce an emulsion by breaking up one of them into tiny droplets. The droplets will then total a large contact area between them.

It is far more difficult to maintain a high rate of reaction between a solid and a liquid. If you place a piece of chalk in a glass filled with distilled vinegar, the reaction will release numerous bubbles of carbon dioxide. However, the reaction will take place only on the surface of the chalk, and it is very small.

The reaction can be speeded up by crushing the chalk. Then the crushed chalk will have a far greater area than the whole piece. Similarly, a faster reaction can be initiated between a powdered solid and a gas. This is why a heap of filings will rust faster than a steel part, and they would do so much faster if they were dispersed in the air. Incidentally, even noninflammable materials, like flour or some metals, are known to have exploded when dispersed in air. This is because fine dispersion vastly increases their reactivity.

This technique, known as pulverization, is employed at large coal-fired power plants. The coal is first finely pulverized, and the powder is then blown with air into the firebox, where it burns almost at once like a jet of gas, producing a strong and hot flame. Pulverized coal burns much faster and more completely than coal in lumps.

Roasting is also a reaction of combustion; during it the sulphur of the copper ore is burned to sulphur oxides. If so, isn't it possible to disperse the crushed and ground ore in air and to burn it much as pulverized coal is burned?

The answer is "yes". This is done in suitably built roasters charged with a bed of powdered ore or concentrate. The bottom of the roaster has a so-called dispersion plate having holes uniformly spaced over its area. Through these holes air is blown into the roaster. Rising through the bed, the air brings the charge into a state resembling the boiling of a liquid. In effect, the material behaves like a fluid, since it can flow from a higher to a lower level. It can be poured into the roaster at one place and out of it at another. That is why technically it is called a fluidized bed, and the process of making a mass of solid particles behave like that is termed fluidization. The fluidized mass displays similarity with liquids in other respects. For example it conducts heat extremely well; as in any liquid there is continuous stirring by convection.

In the fluidized bed the surface of each particle is constantly blown over with air, and the roasting proceeds at a very high rate and to completion. While in mechanically rabbled roasters the treatment occupies several hours, in a fluidized-bed roaster it is completed in a matter of a few seconds.

Fluidization is a new process. It was first introduced in the fuel industry as a way of gasifying coal. Today, it is finding ever new uses where reactions between solids and gases should be speeded up. In fact, it is making dubious the use of multiple-hearth roasters for roasting sulphide copper ores.

FROM ROASTED CONCENTRATE TO PURE METAL

After roasting, the copper concentrate with an addition of lime as flux is charged into a reverberatory furnace where it is smelted to a matte. Reverberatory furnaces can be fired with pulverized coal, liquid or gaseous fuels. The gases leaving the furnace are at about 1200°C. Instead of being discharged into the atmosphere, they go to a so-called waste-heat boiler to generate steam. One-third to about half the heat produced by the combustion of the fuel is recovered in waste-heat boilers.

The molten products tapped from the furnace are the slag and the matte. The matte is usually made up of about one-fourth copper, as much iron, about one-third sulphur, silver, gold, nickel, and so on.

The slag may be either dumped, or processed into building materials. The molten matte is poured into ladles, and the ladles take it to copper-matte converters. They are similar in action to those which turn pig iron into steel, but are different in shape. Bessemer converters are pear-shaped vessels, while copper-matte converters look more like barrels placed on a side.

But the shape of the vessels is not the only thing that sets them apart. The objective of bessemerizing pig iron is to eliminate six to eight parts of impurities in a hundred at the most. The sulphur and iron that must be removed by converting the copper matte account for seventy to eighty parts in a hundred. Naturally, this cannot be done within minutes, as in pig-iron conversion. Copper-matte conversion usually occupies anywhere from ten to over twenty-four hours.

Pig iron is bessemerized at about 1500°C. The temperature for converting the copper matte is 1200°C. Very little slag is produced in the Bessemer process. The copper matte yields so much slag that it has to be run off several times.

The converting operation brings down the sulphur and iron content to a few fractions of one part in a hundred, and yields what is termed crude or blister copper. It has about one or two parts of impurities in a hundred. The impurities, on top of iron and sulphur, are nickel, antimony, lead, gold, arsenic, and silver.

The other products of the converting operation are slag, the coarse and fine dust caught in dust-precipitators, and gases. They are all valuable products in their own right. The gases, mainly sulphur oxides, go to make

sulphuric and sulphurous acid. The fine dust caught in the electrostatic precipitators is sent to specialized factories for recovery of lead, zinc, and other values. The coarse dust caught in cyclones is returned to the reverberatory furnace.

The slag, which contains up to three parts copper in a hundred, is either returned to the reverberatory furnace or smelted in other types of copper-smelting furnaces.

But the most valuable product is, of course, crude or blister copper, which is cast into pigs.

The fifteen parts in a thousand of impurities in blister copper have an adverse effect on the mechanical properties and electrical conductivity of the metal. Also the bulk of these impurities is made up of the precious metals. This is why blister copper is first treated by fire refining and then by electrolysis. The former eliminates the impurities, and the latter recovers the precious metals.

Fire refining is done in reverberatory furnaces. Of special interest is the final stage of the operation. When the metal in the bath has been skimmed clean, poles of green wood are inserted into it. The products of dry distillation formed agitate the contents and drive out the sulphur dioxide and other gases. This operation is called poling-down. Then coke or charcoal is spread on the surface of the bath, and another pole is inserted in order to reduce the cuprous oxide to metallic copper.

Fire-refined copper, now said to be "tough pitch", contains not more than three to five parts in a thousand impurities and is ready for casting. In some cases every ton of copper may carry up to three kilograms of silver and 200-300 grams of gold. For their recovery and in order to obtain still purer copper (for better electrical conductivity) tough-pitch copper is electrolyzed.

Copper anodes are placed in a tank filled with a solution of copper sulphate to which some sulphuric acid is added to give the desired quality of electrolyte. The cathodes are pure copper starting sheets suspended between the anodes. As current is passed through the electrolyte, the anodes are dissolved, and the copper ions discharge at the cathodes to form a deposit of pure metal. The impurities, among them selenium, settle at the bottom as slime.

Slime treatment for recovery of the precious metals is a complex metallurgical process. At the end it produces doré silver, an alloy of gold and silver. The two noble metals are "parted" also by electrolysis. The doré silver is cast into anodes which are suspended in muslin bags. The muslin passes the dissolved silver but catches the undissolved gold. The silver is deposited at the cathodes, thin strips of stainless steel, as a loose mass of crystals easy to remove.

The gold remaining in the muslin bags is a brittle brownish black mud, known as black gold. It carries two-thirds to more than four-fifths gold metal. The black gold is washed and remelted into anodes for gold refining.

During gold refining the other precious metals, present in the original copper ore in negligible amounts, also pass into solution, among them platinum and palladium. Osmium, iridium and silver are thrown down as a residue. They are then recovered in pure form by a separate treatment.

The slime also carries a good deal of the rare metals selenium and tellurium. When the slime and doré silver are heated and melted into anodes, the selenium goes away with the gases. It is caught by suitable dust-catchers, and the dust is then given special treatment which also yields tellurium metal.

So we've come to the end of our tour of copper manufacture, very brief and skipping. Yet we've been able to notice that it yields many other products in addition to copper.

Thus the gaseous sulphur oxide produced by roasting is an excellent source material for the manufacture of sulphuric acid, a vital chemical to many users.

The heat carried by the flue gases of the reverberatory furnace is utilized in waste-heat boilers to generate many kilowatt-hours of electricity at practically no cost at all.

The slags of copper smelting can, and are, made into a variety of building materials.

The slime of copper electrolysis, actually a waste, contains so much of the precious metals that they fully pay all the expenses involved.

This is why present-day smelteries are integrated works turning out all of the products we've just listed and some more. This yields cheaper copper and bigger profits.

BRASSES AND BRONZES

Bismuth and lead are the most harmful of all the impurities present in copper. They do not form solid solutions with copper and, on solidification, are thrown out as thin streaks between the copper crystals. Because of this copper becomes brittle and fragile. This is why the bismuth content in copper should not exceed two parts in a hundred thousand. With one part bismuth in a thousand, copper becomes so brittle that it goes to pieces at a single blow.

The impurities phosphorus, arsenic and antimony impair the electrical conductivity of copper. Two parts phosphorus in a thousand reduces it by one-fifth, and with four parts phosphorus in a thousand the electrical conductivity is only one-sixth of what pure copper has.

Hydrogen has a peculiar effect on copper. When heated, copper readily picks up hydrogen. Once in the intercrystalline space, the hydrogen combines with the oxygen of the oxides which are always present there. Thus water is formed, and the water vapours break up the metal, producing tiny hair cracks. The reduction in the mechanical properties of copper for this reason is known as hydrogen embrittlement.

Now let us turn to copper-base alloys.

A great number of copper-base alloys have been obtained and investigated. The most important ones to engineering are brasses, or alloys of copper and zinc, and bronzes, or alloys of copper and tin.

Bronzes were the first to be produced by man. Ancient metallurgists were good at making them. Believe it or not, they added exactly as much tin as is considered best today, eight to ten parts in a hundred.

Bronzes are classed into two large groups, wrought bronzes and cast bronzes. Wrought bronzes contain seven or eight parts tin in a hundred and can be easily worked mechanically both cold and hot. Cast bronzes are excellent foundry materials—they fill moulds well and shrink on solidification very little.

Many bronzes are alloyed with other elements. Small additions of zinc improve resistance to corrosion in sea water, and make the material very fluid when molten. Tin is added to bronzes which go to make rubbing parts. However, tin is a costly metal, and metallurgists have since long been looking for substitutes. Thus low-tin and even tinless bronzes have come into use, alloyed with aluminium, silicon, manganese and some other metals instead of tin. Some of them have proved superior to tin bronzes in resistance to corrosion and mechanical properties.

Aluminium bronzes contain about ten parts aluminium in a hundred and, sometimes, small amounts of iron or manganese. They are stronger than tin bronzes, but are of lower castability.

Silicon bronzes carry two to five parts silicon in a hundred and are much cheaper to make than tin bronzes.

Manganese bronzes have the highest resistance to corrosion of all bronzes and show excellent ductility.

Beryllium bronze, after it has been suitably heat-treated, tops all non-ferrous metals and alloys in tensile strength, taking a load of up to 130-150 kilograms per square millimetre.

Bronzes have a great variety of applications. Lead bronzes, running twenty to thirty parts of lead, go to make bearing liners. Manganese bronzes, indifferent to heating as high as 400° or 450°C, are manufactured into steampipe fittings. Aluminium bronzes do well as gears, bushings, valve seats and all other components which have to work in the face of heavy friction and high temperature.

Brasses are essentially alloys of copper and zinc, but for special purposes small amounts of other metals, such as aluminium, iron or manganese, are sometimes added to obtain desired strength, hardness or resistance to corrosion.

As a rule, brasses are cheaper than bronzes, because zinc is cheaper than copper. Therefore as much zinc is used in a brass as practicable. Brasses are strong enough and can be worked readily both cold and hot.

A line of zinc-copper alloys containing from three to twenty-eight parts zinc in a hundred are known as tombacs. Their resistance to corrosion is so good that they are used as a coating material for other metals.

The colour of brass changes with zinc content. So-called Dutch metal, also known as Dutch or German brass, contains about twenty parts zinc in a hundred and, because of its golden colour, is used in the manufacture of cheap ornaments. This alloy is also rolled or hammered into thin foils for use as a substitute for gold leaf.

Brasses containing not over thirty-eight parts zinc are particularly suitable for working cold. If there is more zinc, the brass will most often be used for casting, or worked by rolling, forging or drawing while hot.

There is a special grade known as naval brass. It contains one to fifteen parts tin, 61 parts copper, and the remainder zinc. It owes its name to the fact that it strongly resists corrosion in sea water.

While the common grades of brass are difficult to machine because of their high toughness, those alloyed with lead can be cut without difficulty, as they produce breakable chips. Bars of lead brass are made into numerous nuts, rings, bolts and similar parts by automatic lathes.

Of course, the family of copper-base alloys is much bigger than you've just learned and their uses in industry are likewise more numerous. Indeed, the ancient metal is still doing the jobs which ought to be handed over to aluminium, plastics or iron.

A NEIGHBOUR AND A COMPANION

In the Periodic Table copper is preceded by nickel. In nature the two metals practically never part, at least in sulphide nickel ores.

The name "nickel" is short for the German "Kupfernickel", a copper-coloured ore from which nickel was first got. "Kupfer" stands for copper and "nickel" for demon, implying the strong feelings of the Saxonian miners of the 16th century about the disappointing nature of the ore which yielded no copper.

Nickel alloys were probably known to man before the present era. The chances are that it was discovered in China, because already in 200-300 B.C. the Chinese knew how to prepare a nickel-zinc-copper alloy. The alloy was

sold to Bactria, an ancient country of Central Asia, where it was made into coins.

Nickel was first isolated by the Swedish chemist A. Cronstedt in 1751, who gave the metal its strange and irrelevant name. However he could not learn anything valuable about its properties because it carried a good proportion of impurities.

It was not until 1804 that the German chemist Richter got pure nickel, a silvery white metal, very tough and malleable. From that time, research into its properties began.

Nickel turned out to be a close relative of iron. It was found to be chemically inactive; in a dry atmosphere it would not appreciably react with oxygen, sulphur or halogens. Only when heated to 500°C would it combine with atmospheric oxygen. It was also learned that nickel could absorb a large volume of hydrogen.

While chemists were busy discovering ever new properties of nickel, engineers made very little progress finding uses for the metal. In the early 19th century nickel was regarded as a precious metal, and jewellers alone had some use for it. From chemists' labs it stepped out into the glistening show-cases, to "rub elbows" with gold and gem stones. Strange as it may seem, it was used as an alloy, the same as discovered by ancient Chinese artisans.

About the mid-10th century nickel was recognized as a metal for coinage and protection against corrosion. Those were truly useful jobs.

Then engineers ventured to marry nickel and iron. Their union proved very happy, for nickel markedly improved the quality of steel. You've already read about nickel-alloyed steels having a multitude of uses, but at first nickel was only added to steels for armour manufacture. So, in the latter half of the 19th century nickel became a war metal.

The wholesome effect of nickel on steels brought about increased interest in it, and its production began to expand rapidly.

In Russia the manufacture of nickel or, rather, ferronickel, a nickel-rich iron alloy, was started by the engineer Danilov in the 1860's, using cupolas. Just tapped from the cupolas, the alloy contained as much as thirty parts nickel in a hundred. By crucible refining its content could be raised to about seventy parts. The fall in prices, however, stopped the production.

It was not until after the October 1917 Revolution that a nickel industry was set up in Russia. The first nickel-smelting factory was built at Ufalei. Its experience went into the design of subsequent enterprises.

At present the Soviet Union has a large nickel industry, for its requirements in the metal are great. Coinage accounts for a small proportion of the total consumption. Much more goes into the manufacture of alloy steels,

nickel silver, Monel metal, and nickelplating. It also finds uses in the food processing, radio and chemical industries, in special storage batteries, and as a catalyst in the hydrogenation of unsaturated organic compounds.

NO EASY WAYS, EITHER!

Iron meteorites, of which there are large numbers in the science collections of many countries, carry eight to nine parts nickel in a hundred. Engineers would be very happy if the Earth's crust had nickel ores as rich as that. Unfortunately, such ores are a great rarity, letting alone native nickel.

Yet it is a fairly abundant metal. The Earth's crust contains about two parts nickel in ten thousand, which is more than, say, copper. But nickel compounds are more scattered than those of copper.

Metallurgists class nickel ores into oxide ores, in which the nickel is combined with oxygen, and sulphide ores, in which the nickel is combined with sulphur. Sulphide ores account for four-fifths of the explored deposits of nickel in the world. As a rule, sulphide ores also contain copper. As often as not, there is as much, or even more, copper as nickel in such ores. Oxide ores usually carry several times as much iron as nickel.

Such are the ores from which nickel is to be extracted. This is done differently at different factories and in different countries, depending on the type of ore, its nickel content, and simply traditions.

Oxide nickel ore is an earthy, soft and damp material. It cannot be directly smelted in the shaft furnace. It will immediately stiffle the flame and block the passage for the combustion gases. Therefore it is first briquetted or sintered. Sintering has been described in one of the previous chapters.

The sinter is charged into the shaft furnace for smelting. The smelting operation yields a nickel matte consisting mainly of nickel, iron and sulphur. The matte is then bessemerized in a converter so as to eliminate its iron. The "converter" or "Bessemer" matte (containing about three-fourths nickel, less than one part iron in a hundred, and sulphur in the balance) is ground and roasted in mechanically rabbled multiple-hearth roasters similar to those used to roast sulphide copper ores. The calcine is again ground in ball mills and roasted in rotary kilns. This operation eliminates the sulphur and leaves practically pure nickel oxide. It is mixed with charcoal and melted in an arc furnace.

The molten nickel from the arc furnace is then either cast into moulds or granulated. This is done as follows. The liquid metal is poured as a thin jet into a concrete-lined pool where cold water is fed continually. The metal

cools and solidifies at once, and the internal stresses break it up into tiny pieces. They are dried and packed in wooden barrels.

However, the greater part of the nickel output goes to alloy steels. Therefore it is hardly necessary to try and get pure nickel in all cases. Metallurgists are content with a product carrying iron in addition to nickel.

This alloy is obtained by melting the nickel sinter in blast furnaces. True, the product is more costly than pig iron, because nickel ores carry much less iron than, say, magnetites. Yet, lean nickel ores containing less than one part nickel in a hundred are more advantageous to smelt in blast furnaces for this iron-nickel alloy than for pure nickel. On top of all, the cobalt and much of the chromium of the ore also pass into the alloy, making it as good as the metal of iron-nickel meteorites.

Still another method for making nickel is to melt rich oxide ores in arc furnaces, using charcoal as the reducing agent. The product is ferro-nickel, an alloy containing half to three-fourths nickel and the balance iron. By subsequent re-melting and refining, this alloy can be turned into electrolytic nickel 99.97 per cent pure.

Oxide nickel ores can also be directly reduced to metal form in rotary kilns in a mixture with a reducing agent. The charge is raised to 1250-1400°C to fuse it and allow the reduction of the iron and nickel. The two metals form pieces measuring from 3 to 30 millimetres across. The charge is then cooled, crushed, and the metals are freed from the slag by mechanical or magnetic separation. By this process nickel ores containing less than one part nickel and ten to twenty parts iron in a hundred are turned into blooms carrying three to seven parts nickel, or as much as there is nickel in iron meteorites.

Oxide nickel ores can also be treated hydrometallurgically, with sulphuric acid or ammonia. The solution goes through a chain of operations which yield metallic nickel.

All of the above processes apply to oxide nickel ores. Such ores, however, are a minority, as compared with sulphide ores.

Sulphide ores can likewise be smelted in blast furnaces, using the ore charge in sinter form. Blast-furnace smelting yields a matte containing nine parts nickel, a little bit less copper, and about twenty-five parts sulphur in a hundred. More often, however, such a matte is obtained by smelting in reverberatory or even in arc furnaces. Whatever the method of smelting, the matte is bessemerized in converters to get a "Bessemer" matte, consisting of copper and nickel sulphides.

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It is no easy job to separate the companions nickel and copper. This is usually done in an electrolytic cell where the precious metals pass into the slime. Another method for separating nickel and copper, known as the Mond process, is based on the ability of nickel to combine with carbon monoxide, forming nickel carbonyl, a liquid which boils at as low as 43°C. When heated to 180-200°C, the nickel carbonyl vapours break down back into nickel and carbon monoxide. The process is carried out in suitably designed and hermetically sealed towers called volatilizers. The volatilizer residue is extremely rich in copper, cobalt, iron and the precious metals. The residue is then treated for the recovery of these metals. The powdered nickel is of very high purity.

Nickel is also separated from copper and other impurities in electrolytical tanks. All these processes are not simple, nor cheap. That is why nickel costs so much.

MONEL-METAL

Don't waste time looking for this metal in the Periodic Table, because it is not an element, but a "natural" alloy. It is called "natural" since it is smelted direct from the ore. Monel-metal contains sixty to sixty-seven parts nickel, twenty-seven to twenty-nine parts copper, two or three parts iron, and one to two parts manganese in a hundred. Sometimes from two to three parts aluminium may be present at the expense of the copper content.

Monel-metal is obtained from the "Bessemer" copper-nickel matte. The matte is crushed, ground and roasted dead to eliminate all of its sulphur. The calcine, still at about 1000°C, is mixed with charcoal and allowed to cool. As the charge cools, much of its copper and nickel is reduced to metallic form. Then more charcoal is added, and the material is smelted in an arc furnace. The molten metal is cast into moulds where it solidifies into Monel-metal. As can be seen, it is much easier to make than pure nickel.

Monel-metal is no "ugly duckling" in the family of metals and alloys. It has a very high resistance to corrosion. It stands up well to attack by sea and fresh water, alkalis, organic acids, and dyestuffs. It has a fairly high tensile strength, from 50 to 80 kilograms per square millimetre, and a quite acceptable toughness. Its melting point is also rather high, being anywhere from 1300 to 1360°C and varying with composition.

That is why Monel-metal finds many uses in electrical engineering, shipbuilding, the chemical and textile industries, and elsewhere. It is made into high-voltage oil-filled cables, thermocouples, medical instruments, ship screws, pump impellers, turbine blades, and hosts of other components. A good proportion of the Monel-metal output is turned out as wire, bar stock, strip and ribbon.

Nickel is justly regarded as one of the most important vitamins of steel. Over four-fifths of the nickel produced in the world outside the socialist countries goes to alloy steels, especially armour for warships, tanks, and armoured cars.

However nickel is not only an alloying element, but also the basis of many alloys having important uses of their own.

One of them is nickelin, the same nickelin of which the heater coil of your electric range is manufactured. It contains one-fourth to one-third nickel, the inevitable impurities manganese, iron and zinc, and in the balance copper. It is widely used for the manufacture of rheostats and other electrical components where high electrical resistance is important.

Other resistance alloys based on nickel are nichromes, containing also chromium and iron. They are remarkable for high corrosion and heat resistance and are therefore used to make industrial heating elements.

Chromel, an alloy of chromium and nickel, and alumel, an alloy of aluminium and nickel, are most widely used as a couple, a thermocouple, that is. You surely know what a thermocouple is. In case you don't, it's a pair of wires making a junction at one end. If you heat the junction while keeping the other ends cold, a current will flow in the wires. This current will increase with increasing difference in temperature between the hot and cold ends. Thermocouples are widely employed to take temperature where mercury thermometers are of no use, such as in electric furnaces.

Permalloy, an alloy of nickel and iron, has a very high permeability and is readily magnetized and de-magnetized even in weak magnetic fields. The alloys in this group are used to make magnetic cores for apparatus operating on a feeble electric current.

Nickel silver, also known as German silver, is the metal of coinage in many countries. It is also used in the manufacture of cutlery and tableware. It has an attractive colour, good resistance to corrosion and good mechanical properties.

The metal that goes to users under the name of commercial nickel is in effect an alloy. For it contains additions of magnesium, manganese and silicon. "Commercial nickel" sounds a bit dull for a metal which resists corrosion better than the noble silver. It is used in critical parts for instruments of high precision, chemical and food-handling equipment. On contact with food, the metal will not contaminate it. It is not toxic, nor will it destroy any of the vitamins, as some metals do.

Silicon nickel contains even less impurities than commercial nickel. It is used in the manufacture of electrodes for electronic tubes.

Manganese nickel differs from its relatives commercial and silicon nickels by increased resistance to heat. This is why it is used in the spark

plugs for aircraft, motor-car and tractor engines. Needless to say how important this job is.

We've been able to mention only some of the members in the family of nickel-base alloys. But even this review, brief as it is, shows how industrious this family is.

BURNING TO ELECTRICITY

Open your flashlight and take out the battery. Remove its paper wrap and look at the metal. If the battery is new, the metal will appear bluish-grey and strong to touch. If it has been in use for a long time, it will show white patches of corrosion and will crumble under your fingers.

The metal is zinc. Burning in the battery of your flashlight, it generates the electric current for the lamp. In a sense, it is the fuel of the power plant you carry about with you.

Zinc had been used in brass for 2,000 years before it was recognized as a separate element. Only the Chinese in the 5th century B.C. knew how to condense zinc vapours and make the condensate into zinc metal.

In Europe zinc metal was first obtained, apparently, by the Swiss physician and natural scientist Paracelsus who lived between 1493 and 1541. In any case, the metal is first mentioned in his writings.

In the beginning of the 18th century the German metallurgist Henckel came out with a consistent process for zinc manufacture. In 1743 the first zinc-smelting factory was built in Bristol. In Russia the first zinc factory went into operation at the end of the 19th century, but a large-scale zinc industry was set up only after the October 1917 Revolution. At present the Soviet Union has many zinc smelteries equipped with up-to-date machinery. They are situated in the Donbas area, Kazakhstan, Siberia and the Urals.

Most often zinc is prepared either by distillation or by electrolysis. Whatever the process, however, everything begins with ore. Usually zinc ores also carry lead, copper, iron, cadmium, the rare and precious metals. Therefore the first step is to separate the ore into concentrates by differential concentration. What goes for further treatment is a zinc concentrate.

In zinc distillation a mixture of roasted zinc concentrate and anthracite screenings or coke breeze is charged into a fireclay retort which is then placed in a furnace heated to 1400°C. In the retort the zinc is reduced and vaporizes. The nose of the retort opens into a fireclay condenser where the retort gas cools in contact with its walls, the droplets run down the sides and fall from the top, collecting in the pool at the bottom. The liquid zinc is drawn from the pool as it accumulates there, and is cast into moulds. The

zinc vapour that escapes from the condenser is precipitated as a dust in the prolong, a sheet-iron extension to the condenser.

Distillation is a very expensive process as it requires much fuel. This is why in the Soviet Union preference has always been given to the electrolytic process. It consists in leaching roasted zinc concentrate with sulphuric acid. The zinc sulphate solution is then purified and electrolyzed. Metallic zinc is deposited at the cathodes, and the solution accumulates sulphuric acid which may be re-used to leach more roasted concentrate. The cathodes are stripped of their zinc deposits, and the zinc is melted into ingots.

Today zinc is produced in large quantities. In 1957 the United States made 709,000 tons of this metal. Belgium, which has no zinc-ore deposits of its own, smelted 215,000 tons, and Canada 229,000. The total production of zinc outside the socialist countries in 1958 was 2,210,000 tons.

Zinc is a weak metal, highly sensitive to temperature variations. At room temperature it is hard and brittle. At 100-150°C it becomes ductile and can be easily rolled into sheet and drawn into wire. It melts at 419.6°C and boils at 906°C. It would seem that a metal like this can hardly find any use. Why is it then that so much zinc is made every year?

This is because zinc has properties which man has come to recognize and highly appreciate. To begin with, zinc is very resistant to attack by dry air. In damp air or in water it comes by a thin film of oxide which protects it from further oxidation. Also, when molten, zinc combines with iron, producing a chemical compound. This property is used in galvanizing, or coating of iron and steel (by hot dipping) as a protection against corrosion. You've probably seen galvanized iron, as it is called. It is made into buckets, washing tubs, and the like. The zinc coating makes a strong bond with the underlying iron and reliably protects it against corrosion. A major part of all the zinc produced in the world is used precisely for this purpose.

Zinc is also used as a constituent of brass, German silver, bronze, type metal, and so on.

Much zinc is used to make dry batteries, battery cans and lithographic plates.

Zinc compounds also serve man. Some are used as paints, others to impregnate railway sleepers against rotting. Still others serve as fillers for rubber, cellulose or plastics or as ingredients in drugs.

THE METAL OF CANS

As Fersman, a prominent Soviet scientist, writes in his *Geochemistry for Entertainment*, "Tin has had its 'bronze age'; today it has become a metal of cans".

That's true. For centuries tin was mainly used as an addition to copper to give bronze, that great alloy. Then the bronze age ended, and bronze lost its position as the major metal. As to tin, it has found another companion, iron. Their union has produced tin plate. Today tin plate has thousands of uses. One of them is in the manufacture of food containers, or cans.

Tin metal is not affected by exposure to air or water at room temperature or by water up to its boiling point. Only when heated to 150°C will tin be oxidized by atmospheric oxygen. All this is more than enough for a metal which is to come in contact with the food preserved in cans.

Tin can be applied to iron plate in several ways. In the past, if tin was needed only on one side, the plate was cleaned, heated from the other side, and rubbed with flux and tin, using a dry and clean rag. This method, however, belongs to history. Today use is made of hot dipping and electroplating.

In hot dipping the plate, cleaned and degreased, is immersed in a bath of molten tin through a blanket of flux. When it is taken out, the plate has a thin coating of tin.

Tin melts at 232°C and boils at 2430°C. Its specific gravity is about 7.3 at room temperature. Tin is soft and can be readily cut with a knife and scratched with a finger-nail. It can be easily rolled into very thin foils. At one time it went to make spoons, plates and even soldiers' buttons. As the story goes, grey coloured spots appeared on the buttons one winter. The grey tin grew and grew until all the buttons turned to dust. It looked as if the tin had contracted some disease, and a name was even coined for it — "tin pest" or "tin plague".

The explanation of tin pest is this. Ordinary tin, as we know it, is stable only above minus 13.2°C. At temperatures below this the stable tetragonal metal (white tin) changes to the cubic crystal structure. Expansion occurs so that the metal grows in volume, extending radially outward, until the metal breaks down to a metal powder. Although the transformation temperature is 13.2°C below zero, much lower temperatures (down to —30°C) are needed to produce the effect. Apparently it was that cold when the soldiers' buttons in the story disintegrated.

We've learned about some of the service tin does to man. Although the metal is not a close neighbour of copper in the Periodic Table, we've taken it up in this chapter. It has been copper's companion for too many centuries and is zinc's counterpart in too many applications to be separated from its workmates.

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VITAMINS FOR STEEL
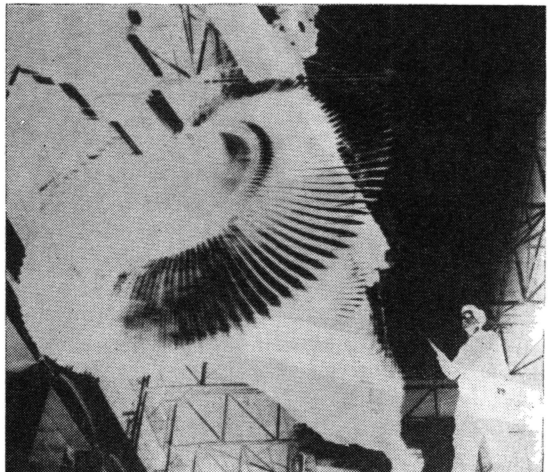
Some eighty years ago the Russian biologist N. Lunin carried out an intriguing experiment. He was interested in what it takes to feed living things properly. He divided his animals, mice, into two groups. One group was fed with plain cow's milk, and the other was given an artificial mixture of all that makes up milk. Lunin had thoroughly purified the constituents so as to avoid mistakes.

The mice in the first group fared well, the animals in the second withered and died. Their food apparently lacked some "trifle" crucial to their survival.

Later, physiologists learned that this "trifle" was vitamins. The organism needs very little of them, but if they are lacking, it loses vitality and decays. A few tiny grains of vitamins added to our diet give strength to our muscles, kindle the flame of life in our eyes, and straighten the stooping shoulders and the bent knees.

Much the same effect is produced by alloying additions on steel. Sometimes several parts in a hundred or even in a thousand of a metal which is often inconspicuous by itself, can change the quality of a steel beyond recognition. Vanadium makes steel capable of resisting endless cycles of bending loads. Tungsten multiplies its hardness. Manganese enhances its resistance to wear. Nickel gives it the remarkable ability to resist corrosion.

Steel began to be alloyed about a century ago. Since then metallurgists have tested many additions and their combinations. There have been failures, but gradually metal-makers have learned how much of which metals can do what. A huge multitude of alloy steels have been developed, possessing a broad gamut of properties good for any use.

Many metals began their careers in man's service as alloying additions to steel. Only after some time and mainly through this use did man come to know them better and find new uses for them. This has happened to tungsten, the strongest and most refractory of all metals, and to titanium, that rival of iron. Others, while still honestly working as additions to steel, are staking claims of their own both in engineering and industry.

In the Periodic Table the most commonly used alloying elements are grouped tightly around iron. Among them are copper, nickel and cobalt occupying the places past iron; manganese, chromium, vanadium and titanium preceding iron; and also molybdenum and tungsten which, although located in other levels of the system, are closely related to the main group. We shall discuss them in this chapter.

MINERS' GOBLIN

In the Periodic Table this metal stands between iron and nickel. Its present-day name is cobalt. Man had been using its compounds for thousands of years before the metal was prepared in pure form.

Already in ancient Egypt and China cobalt compounds were used to give glass and glaze a blue tinge, unusually beautiful and fast. But ancient and medieval metal-makers could not extract cobalt metal from its ores. In that these ores, looking so much like the ores of other metals, would not yield any of them, German miners suspected the tricks of Kobold, a goblin haunting their mines. When in 1735 the Swedish chemist Brandt isolated cobalt metal, he gave it the name cobalt after that goblin.

In the 18th and 19th centuries cobalt had almost no uses other than in pigments for glass and ceramics. In contrast, the 20th century has found a multitude of applications for the goblin's metal.

In appearance, though, there is nothing weird about cobalt. Pure cobalt is a silvery white metal with a slightly reddish tinge, tenacious and malleable. It melts at about the same temperature as iron (1490°C) and boils at 3185°C.

At room temperature dry air does not attack cobalt. Only when heated to 300°C does a thin film of oxide appear on it. However, powdered cobalt (which can be obtained by the reduction of cobalt oxide with hydrogen) will ignite in air at as low as 250°C.

Cobalt has the peculiar property of absorbing hydrogen. A piece of metallic cobalt will take in thirty-five times its volume of hydrogen, and powdered cobalt as much as one hundred times.

Cobalt compounds are found in many copper, nickel and manganese ores. Cobalt is recovered as a by-product from the slags, mattes and calcines of these ores. Usually cobalt is leached out of them with acidic water. Then follows the complicated process of separating the cobalt from its companions.

Cobalt production is expanding all the time, though not so rapidly as that of other metals. While in 1900 world output was only 354 tons, in 1947 the figure was 6,200 tons (leaving out the Soviet Union).

Cobalt alloys show a multitude of remarkable properties, a factor which has stimulated their use.

An alloy containing thirty-five parts cobalt and fifty parts iron in a hundred together with some other elements has the highest saturation induction of all metals.

An alloy of cobalt and platinum, after suitable heat treatment, has a very high coercive force, that is, it is very difficult to demagnetize.

Other cobalt alloys are known which show remarkable magnetic properties and go to make permanent magnets and electrical components. Among them are the widely known Magnico and Alnico.

A further group of alloys in this family includes heat resistant alloys, exemplified by the alloy vitallium. It contains sixty-five parts cobalt, twenty-eight parts chromium, six parts molybdenum, and also a few fractions of one part carbon, iron and nickel in a hundred. This alloy has the property of maintaining high tensile strength at up to 800°C and operating for a long time at up to 900°C if the stress is reduced.

Vitallium is used to make blades for turbo-compressors, gas turbines, jet engines, and components for high-pressure, high-temperature boilers. It is a favourite with engineers, and they would use it still more if cobalt were a bit cheaper.

Heat-resistant alloys of cobalt are also employed as binders in sintered or cemented carbides prepared by powder-metallurgy techniques.

As an alloying element, cobalt is added to a long line of steels. If it is to show its alloying properties, however, cobalt must be added in fairly large quantities, usually five to ten parts in a hundred, although sometimes as much as twenty parts may be used. Because of this, cobalt steels are being used on a limited scale. Yet there are high-speed tool steels containing up to ten parts cobalt, as well as magnetic and heat-resistance steels also containing cobalt.

Still wider use is made of cobalt compounds. The attractive blue and violet pigments used in porcelain, glazes and enamels and readily dissolv-

ing in glass are cobalt compounds. The violet, yellow and green pigments employed in other industries are also cobalt compounds.

Cobalt chloride has the unique property of changing in colour with temperature and humidity. Just try and dye a shirt with cobalt chloride. In dry weather it will be blue. After a rain, although not a drop has fallen on it, the shirt will show crimson. Cobalt chloride in solution gives so-called invisible ink. Write something on a sheet of paper in this ink, allow it to dry, and not a trace will be left visible on the paper. But when you heat the paper over a flame, bright blue letters will stand out.

Salts of cobalt are used as catalysts for some chemical reactions, in medicine and in photography.

Cobalt compounds used as trace fertilizers have a truly miraculous effect. Their addition to soil does not increase its fertility, but the amount of cobalt in the plants grown on that soil increases. This is very important, because cobalt deficiency results in cattle and sheep showing long rough coats, scales on the skin, loss of flesh, inability to coordinate movements, gauntness, slow growth, and decreased milk flow. Sometimes, cobalt is added direct to the animals' diet.

What has been said about it does not imply man has learned every-thing about cobalt. Many more uses are just awaiting their discoverers.

IRON'S INSEPARABLE COMPANION

The square to the left of iron in the Periodic Table is occupied by man-ganese. It is a very abundant element, accounting for 0.09 per cent of the Earth's crust by weight. But it never occurs native.

Manganese ores have been found in many countries, including India, Brazil, West Africa, and the Union of South Africa. The biggest deposits, however, have been discovered in the Soviet Union. Manganese is mined near Nikopole in the Ukraine, at Chiatura in Georgia, in Western Siberia, the Southern and Northern Urals, Kazakhstan, and elsewhere.

Metallic manganese was first obtained by the Swedish chemist Hann in 1774, but it was not until 1807 that the metal was named "manganese" by A. Scherer of Russia.

Pure manganese is a silver-coloured metal, very brittle. It melts at 1245°C and boils at 2027°C. At room temperature air does not attack it. On heating, it combines with all non-metals and forms alloys with all metals.

The extraction of manganese metal is no easy job. When reduced with carbon from the oxides, it combines with the carbon to produce carbides contaminating the metal. Relatively pure manganese metal can only be got by the alumothermic process, in which powdered manganese oxide is

mixed with powdered aluminium, and the mixture is ignited. The aluminium robs the oxíde of its oxygen, thus reducing it to metallic form. Manganese metal can also be extracted by electrolysis.

Most of the manganese used in industry, however, is not extracted as the metal. Over nine-tenths of the output is used to deoxidize, desulphurize or to alloy steels and irons, to deoxidize brass, bronze, nickel, silver and Monel-metal. A manganese content of thirteen to fourteen parts in a hundred makes steel especially wear resistant. But the manganese used for these purposes need not be pure. It will serve well as an alloy containing seventy to eighty parts manganese, the balance iron and carbon. The alloy is manganese iron carbide, known as ferromanganese.

Ferromanganese is smelted from manganese ore in ordinary blast furnaces run at a temperature higher than is usual for iron. High-quality ferromanganese used to deoxidize alloy steels is prepared in arc furnaces.

Metallurgists took so little interest in manganese proper that they did not know anything important about its own alloys for a long time. "It's a brittle metal unsuitable for independent use," they said. "It's only good as an addition to steels." In 1917, the Russian scientists Zhemchuzhny and Petrashevich found that even a small addition of copper, about three parts in a hundred, would make manganese ductile. Further research showed that additions of nickel, iron and cobalt would also work the same way.

Today metallurgists know that, in addition to some special properties, manganese-base alloys have excellent mechanical properties. An alloy of nine-tenths manganese and one-tenth copper has an ultimate tensile strength of 55 kilograms per square millimetre. That's not bad at all! Other magnesium-base alloys can well replace brass, German silver and other metals.

Alloys of manganese, copper and nickel cannot be called "chiming". Nobody casts bells of them. If such a bell were cast, no peal would come from it. A blow at it would give a dull, short sound. This is because vibrations quickly die out in the metal. This is called damping, and manganese-base alloys display it to the full extent.

Such is manganese, the eternal companion and neighbour of iron.

WHERE ACIDS ARE POWERLESS

Chromium, standing next to manganese in the Periodic Table, eluded man for a long time. It was discovered by the French chemist L. Vauquelin in 1797 in the red Siberian mineral crocosite, or lead chromate, a sample

of which had been brought to Paris by the Russian scientist Pallas. In pure form, however, it was not obtained until 1854.

Chromium is a steel-grey metal with a bluish tint. It is hard and brittle. Probably everyone is familiar with it in the decorative and protective mouldings of motor cars, motor cycles, and bicycles. But very few know that blood-red ruby and seawater-green emerald owe their colour to the presence of chromium. Incidentally, Vauquelin named the element chromium because of the brilliant and diverse colours observed in most of its compounds (from the Greek for "colour").

The melting point of chromium is 1910°C, or higher than that of most of the metals close to iron or copper, but it boils at as low as 2480°C.

Unlike manganese, impurities make chromium brittle. But it becomes more ductile and easier to work as their content decreases.

Chromium does not tarnish. You don't worry when the wheels of your bicycle get splashed with mud carrying all sorts of aggressive substances. You just rub them with a wet rag, and they shine again as new, showing no trace of rust. Even nickel would come by a dull film of oxide under such conditions, but chromium does not.

Naturally, the bulk of the chromium produced is used up in metallurgy. Like nickel, it is a very important vitamin of steel. And like manganese, it is not used as the metal, but as an iron-chromium alloy named ferrochrome. It is obtained by reducing chromium oxide with carbon in arc furnaces. For greater purity ferrochrome may be given additional treatment. In all cases, however, it must have at least sixty to sixty-five parts chromium in a hundred.

Much chromium is used in the manufacture of a large variety of components for machines, mechanisms, and household appliances. Pure chromium for these applications is obtained either by the thermit process, in which chromium oxide is reduced with aluminium at high heat, or by electrolysis of some of its salts.

Additions of chromium to steels give them exceptional hardness. Tool steels often contain six to fifteen parts chromium in a thousand. Such steels go to make drills, cutting tools, threading dies, screw taps, surgical instruments, razor blades, and the like. The hardness chromium gives to steels makes them very suitable for fabricating ball bearings. Chromium also makes steels resistant to heat, acids and corrosion. The proportion of chromium in them is much greater than in tool steels. Stainless steel contains about twelve to eighteen parts chromium in a hundred, and heat-resistant chrome steel twenty-five to thirty-five. These grades of steel are used to make components for steam turbines, high-pressure boilers and similar equipment.

Chromium is also a constituent of non-ferrous alloys such as Nichrome (nickel and chromium) and Stellite (chromium, cobalt, and tungsten). The

name "Stellite" covers a whole series of alloys used for cutting tools in which the hardness is an inherent property of the alloys and is not induced by heat treatment. The alloys are very resistant to corrosion and abrasion and retain their hardness at a red heat.

Not all of the chromium ore mined is processed into chromium metal. A large proportion is made into chromite bricks used to line high-temperature furnaces, because the material melts only at about 2200°C.

Many uses have been devised for chromium compounds. They include pigments, dyestuffs, photographic materials, catalysts for some chemical processes, and drugs.

Yet the principal job for chromium is to improve steel when added as an alloying element and to protect it when used as a coat.

In the future it may well happen that chromium will be given some independent jobs in the powerful ensemble of metals used by man.

NOT FOR GUNS ALONE

The ore of this metal was at one time made into leads for pencils, so soft it is. In recent time, after man has learned how to separate it from the impurities, the ore has come to be prepared into lubricating grease. As four centuries ago, it still vies with graphite in usefulness to man.

In appearance the ore, called molybdenite, closely resembles galena, a lead ore. In fact, the name molybdos (lead) was applied by the Greeks to galena and other lead ores and, up to the 18th century, to the mineral molybdenite because of this similar appearance.

But there is nothing "soft" about the metal molybdenum extracted from this ore.

In 1778 the Swedish chemist Scheele treated molybdenite with nitric acid and obtained a white residue. The residue proved to have acidic properties, so he called it "acidum molybdenae".

In 1790 Hjelm isolated the element molybdenum as a metallic powder by heating molybdic acid with charcoal. Pure molybdenum was obtained, however, only in 1895.

In the Periodic System molybdenum is located right below chromium. Therefore it is similar to chromium in chemical properties, but greatly differs from it in physical ones.

Of specific gravity 10.3, molybdenum is heavier than chromium. It melts at 2620°C and boils at 4700°C. It is very hard and tough. When drawn into wire, it has an ultimate tensile strength of 140-200 kilograms per square

millimetre. Even annealed molybdenum wire can stand up to a load of 90-120 kilograms per square millimetre.

At room temperature air does not attack molybdenum. At 500-600°C, however, the oxidation goes on so violently that the metal becomes irridescent. Many acids have no effect on molybdenum.

In Russia molybdenum became an important alloying addition when in 1886 a steel alloyed with about four parts molybdenum in a hundred was prepared at the Putilov Works in St. Petersburg. The addition had improved the properties of the steel so much that metal makers in other countries took interest in molybdenum.

In 1890 a process was proposed for making ferromolybdenum by reducing molybdenite with silicon or aluminium. The new alloy soon rose to prominence in the manufacture of alloy tool, structural, stainless and other steels. Today over nine-tenths of the molybdenum produced is used as alloying additions to steels.

Pure metallic molybdenum in powder form is prepared by reducing molybdenite with hydrogen. The powder is then compacted, sintered, machined and heat-treated. It is manufactured into ribbon, wire and a variety of pressed components. Most often they can be seen in radio valves. The wires supporting the tungsten filament of an ordinary lamp are also made of molybdenum. Everyone can see them, but probably very few know why molybdenum has been chosen for this service. The point is that pure molybdenum expands on heating and shrinks on cooling as much as hard glass, and the surface oxide dissolves in the molten glass, making an effective seal.

The production of molybdenum has had its ups and downs, but the general trend has been to make more and more of it, especially in time of war. In 1900 the whole world produced as little as one ton of molybdenum. In 1914 the figure was 150 tons. In 1916 molybdenum production expanded to 300 tons. In 1921 it fell to 120 tons. In 1943 the world outside the Soviet Union made 30,500 tons of the metal, and in 1945 its production dropped again to 16,000.

However, molybdenum is good not only for guns. Gears, shafts, boiler plate and turbine components are also made of molybdenum steel.

Before the October 1917 Revolution Russia had not so much as an embryo of molybdenum industry. Now the Soviet Union is making so much of this metal that it is no longer imported.

Molybdenum metal powder, after it has been made by a suitable process, is pressed into bars, baked and sintered. The bars, each weighing about a pound, are swaged and drawn into wire or rolled into sheet down to 0.5 mm thick.

Carl Wilhelm Scheele, pharmacist and one of the greatest experimental chemists of all time, was born in Stralsund, Pomerania, of Swedish parents in 1742 and died as a member of the Swedish Royal Academy of Sciences in 1786. He made quite a number of brilliant discoveries during his short life. He was the discoverer of oxygen. To him we owe the first knowledge of chlorine, the individuality of manganese and some of its compounds, and barium hydroxide. He introduced the world to hydrofluoric, nitro-sulphonic, molybdic, nitrous, and fluosilicic acids in the inorganic field and to lactic, gallic, pyrogallic, oxalic, citric, tartaric, malic, mucic and uric acids among the organic substances.

He was also the first to extract tungstic acid from the tungsten mineral scheelite (named after him) in 1781. Two years later d'Alhujar extracted tungstic acid from wolframite and reduced it to "wolfram" powder by heating with charcoal. For about a century tungsten remained a useless metal. It was not until 1868 that Robert Mushet, an Englishman, first added tungsten to steel. His steel, called Mushet's, self-hardening, or air-hardening steel, contained over five parts tungsten in a hundred and was used for machine tools.

Before him, the cutting speed did not exceed five metres per minute. At higher speed, the tools would soften and grow dull. The cutting tools made from Mushet's steel raised the speed by half as much again. In a way, it was a sort of high-speed steel.

Genuine high-speed steel came along forty years later. It had eight parts tungsten in a hundred and could cut at a rate of up to eighteen metres per minute. A few years later it was raised to thirty-five metres, a seven-fold increase.

That was a limit for steels. Instead, "hard carbide" cutting tools took over. The first "hard carbide" made of tungsten carbide and cobalt was born in the Krupp laboratory in 1907. With them the speed of cutting rose to 45 metres per minute. Today it is as high as thousands of metres. As in the early types, the present-day materials mainly consist of tungsten carbide, which is among the hardest substances known.

Tungsten was the first alloying element to be added to steel. One of its early uses in this capacity was in making gun barrels. It sharply improved their durability. German engineers were quick to appreciate it, and in the first world war the German-made light guns could stand up to 15,000 shots, while the French guns would fail after eight thousand. Tungsten output in those years surpassed that of nickel, antimony and many other elements, rising from 200-300 tons a year at the turn of the century to 32,000 in 1918. In 1921, though, it again dropped to five thousand. In 1941 about 47,000 tons of tungsten concentrate was prepared in the world outside the

Soviet Union. Its main suppliers are China, Burma, the United States, Bolivia and Portugal.

Today four-fifths of the tungsten produced goes to alloy high-strength steels. About one-seventh is manufactured into sintered carbides. The remainder is made into ductile tungsten, a metal possessing remarkable properties.

To melt it, you'll have to raise it to 3410°C. Very few metals will remain liquid at this temperature. Most of them will boil at a much lower point.

Tungsten boils at 6000°C. Even on the Sun's surface it would remain liquid, without changing to a gas.

Tungsten is the strongest of all metals. Its ultimate tensile strength is 400 kilograms per square millimetre, and it retains this fantastic strength to as high as 800°C!

At the same time tungsten metal has an enviable ductility. It can be drawn into a wire eighty kilometres of which will tip the scales at only 200 grams.

For use as an alloying addition to steels, tungsten is prepared as ferro-tungsten by reducing its ore with carbon in arc furnaces in the presence of iron scrap and flux. Pure tungsten is made by reducing tungstic acid to metal powder with hydrogen or carbon. The powder is then compressed, the compacts are baked and sintered, and the sintered bars are finally drawn into filaments for electric lamps, pressed into components for electronic valves, X-ray tubes, contacts for resistance and atomic-hydrogen welding, and other components which are to work at very high temperatures.

Such is tungsten, the strongest and most refractory of all metals, ready to bear the brunt of the searing heat in machines and devices built by man.

A NEIGHBOUR OF THE NOBLES

Many claims regarding the discovery of element 75, a homologue of manganese, have been laid. The first who discovered or rather predicted it as "dvi-manganese" was Mendeleyev. Then its discovery was reported by Kern in 1877, by Barrier in 1894, Ogawa in 1908, and so on. It is not unlikely that some of the investigators did run into "dvi-manganese", but they could not produce confirming evidence, and the puzzle remained unsolved.

In 1922 the German chemists Walter Noddack and Ida Tacks began their systematic search for homologues of manganese. Using one kilogram of an ore containing molybdenum, tungsten, ruthenium and osmium, they isolated 0.2 gram of their alloy. Spectral analysis showed the presence of one more, unknown element. The investigators announced their discovery in 1925 and named it "rhenium" in honour of the Rhine.

Rhenium is a heavy metal (heavier than gold, for its specific gravity is 20), silvery white in colour. It is very refractory. Only tungsten melts at a higher temperature. Rhenium has to be raised to 3170°C to melt and to the fantastic 5870°C to boil.

Rhenium is exceptionally stable chemically. Even at 1500°C, it reacts with oxygen but little, surpassing tungsten itself in this respect. It disintegrates less than tungsten at high temperature, the reason why tungsten filaments are sometimes given a coating of rhenium. It has been reported that rhenium also exceeds tungsten in strength at a red heat.

Acids do not attack rhenium, for which reason attempts have been made to add it to stainless steels. Probably it will become an important vitamin of steel with time. It may also become a common material for thermocouples. A number of other possible applications of rhenium metal have been suggested, but because of the high cost and present rarity of the element none has received any widespread commercial use.

Rhenium is a typical trace element. Only some of the molybdenum ores contain sometimes as much as one part rhenium in ten thousand. This is why before the second world war all the rhenium of commerce was extracted from the molybdenite residues. At the present time the only known commercial source of rhenium is the flue dust from the roasting of molybdenite.

Although the neighbours on its right are the noble metals, rhenium is more a workmate of steel's helper, tungsten, which is its neighbour on the left.

THE KEY TO STAMINA

"If it were not vanadium, I'd not have built my car", Henry Ford is rumoured to have once said.

"If it were not vanadium, some groups of animals would not exist," zoologists insist, telling us that the blood of holothurians contains as much as ten parts vanadium in a hundred.

These two opinions are quoted in Fersman's poetical essay on vanadium, a metal which, despite its abundance, kept eluding man for a long time.

The history of this metal is unusual. In 1801, Andres Manuel del Rio reported a new element on the basis of a compound he prepared from the ores at Zimapan, Mexico. He named the element "erythronium" from the Greek "erythros" (red). However, his discovery was not accepted and he later became convinced that his material was a basic lead chromate.

Thirty years later N. G. Sefstrom of Sweden discovered and proved the existence of a new element which he called "vanadium" after Vanadis, the Scandinavian goddess of youth and beauty. At about the same time, F. Wach-

ter, who was re-examining the ores from Zimapan, found that the element reported by del Rio was the same as the vanadium of Sefstrom.

But it was not until 1869 that the Englishman Roscoe prepared metallic vanadium, though with more than four parts impurities in a hundred. And impurities, even when present in minute quantities, sharply change the properties of vanadium. In pure form, it is brilliantly white and very hard, yet malleable. A small addition of impurities, especially nitrogen, oxygen or hydrogen, markedly reduces its ductility; it becomes very brittle.

It must be noted, though, that the mechanical properties of pure vanadium have been investigated very little. For in no country of the world is it produced on a commercial basis in the pure state. Only in laboratories can you find specimens of pure vanadium.

For all of these limitations, vanadium may well play a solo part in the orchestra of metals used by man. It is strong, resistant to corrosion up to 300°C, and melts at about 1700°C. It is lighter in weight than iron, having a specific gravity of nearly 6. It is more abundant in the Earth's crust than cobalt, molybdenum, copper, lead or tin.

So the time may come when vanadium will be a common structural metal. It will be made into components for machines and structures exactly as they are being made from steel and aluminium. There will be as many and as well-known alloys of vanadium as there are those of copper and iron today.

Today, however, vanadium is being used only as an alloying addition. Over nine-tenths of the total vanadium output is used up by the iron and steel industry.

Usually as little as fifteen to twenty parts vanadium in ten thousand is added to steel. It has a cleansing effect on the steel, because vanadium is a good deoxidizer. At the same time, the steel gains in strength and elasticity. It never becomes tired of elastically counteracting any force tending to bend it, as if it learns from vanadium how to preserve endurance and to multiply its stamina many times. This is why vanadium is always added to spring steels. Vanadium also increases the resistance of steels to oxidation and has an arresting effect on shrinkage porosity in castings. Vanadium steels are employed in the automotive, aircraft and other engineering industries.

Steel is not the only metal to benefit from additions of vanadium. Cast iron, too, is markedly improved by this "vitamin". Vanadium cast irons make excellent steam cylinders, piston rings, moulds, rolling-mill rolls, cold-pressing dies, and similar products.

In 1907 the world output of vanadium was about three tons. In 1943 the figure rose to 4,300 tons (without the Soviet Union). Since then, vanadium production has been oscillating about that figure. All, or almost all, of this output is made as ferrovanadium. In the Soviet Union it is got from iron ores as they are smelted to steel.

Many Soviet iron ores contain ten to sixty-five parts vanadium oxides in ten thousand. This is much. In blast-furnace smelting, nearly all the vanadium passes into the pig iron. When the iron is converted to steel, the vanadium is made to pass into the slag. Sometimes the slag carries eight to sixteen parts vanadium oxides in a hundred. The slag is then crushed, ground, mixed, roasted so as to convert the vanadium to soluble compounds, and finally leached. The leach is then precipitated, and the residue is smelted to ferrovanadium, containing approximately one part of vanadium and two parts of iron.

Wide use is made of vanadium compounds. Pentavanadate (V_2O_5) is an excellent catalyst in the manufacture of sulphuric acid. Other compounds are employed in medicine, photography, textiles, paints and varnishes, and glass manufacture.

This is, of course, only a beginning in the great service vanadium is going to render to man. It is working at less than full power, not even at half-power. This metal is capable of doing bigger things.

What stands in the way of using vanadium on a large scale is only the lack of concentrated vanadium ores. It is very abundant, but scattered. The problem is how to gather it.

IRON'S RIVAL

The very word "titanium" suggests something powerful and undestructible. You recall at once the gods of ancient Greece, the twelve gigantic children of Uranus (Heaven) and Gaea (Earth), who made war on Zeus himself. Vanquished, they were hurled below the lowest depths of Tartarus (the nether world). As Greek myths tell us, the son of the Titan Iapetus, Prometheus, stole fire for them from heaven. To punish him, Zeus chained Prometheus to a rock in the Caucasus where a vulture fed each day on his liver, which was restored in the night.

But when in 1795 the German chemist Martin Klaproth discovered it, he knew nothing about its remarkable properties. In fact, what he had obtained from the mineral rutile found in Hungary was not a metal but an "earth" (an oxide), and this suggested to him, as he admitted, the name "titanium" from the Titans, the mythical first sons of the Earth.

Nor was Klaproth the first to deal with titanium. Four years before him the Reverend William Gregor, who was also an amateur chemist and mineralogist, analyzed the black sand along the beach in Cornwall. The analysis showed nearly fifty parts in a hundred of a white metallic oxide up to that time unknown. His priority was acknowledged by Klaproth, yet we do not even remember the name Gregor gave to his finding.

The fact that the two chemists found the same metal in different rocks shows how abundant titanium is. And it is abundant. Accounting for 0.6 per cent of the Earth's crust by weight, titanium is the ninth most abundant element. Of the metals suitable for structural use it is exceeded in amount only by aluminium, iron and magnesium. Titanium is three times as abundant as manganese, chromium, vanadium, zinc, nickel and copper taken together.

For all its abundance, it was not until 1910 that titanium metal was first obtained. The first few grams of the metal were not particularly pure, and low-purity titanium could only be produced for many years. That was why word got round in the metallurgical world that titanium was a weak, brittle and useless metal which could not be worked. And so it remained as an alloying addition to steel and a source material for white paint for a long time.

In recent years, however, metallurgists have investigated its properties more closely, and the ill fame has been dispersed. For titanium has proved to be superior to many of the older metals. Thus, it is only about half as heavy as iron, but is stronger than carbon steels and approaches in strength the best stainless steels.

This is a major advantage. To get an idea of what it promises, suppose the turbine blades in a turbojet engine are made of titanium instead of steel. This will cut down their weight by two-fifths. Since the rotor has become lighter in weight, you can use smaller bearings. The lighter rotor makes it easier to start up and bring the engine to speed. The plane can also be made lighter in weight with a proportionate increase in range, altitude, speed, and payload.

Titanium melts at a very high temperature, 1680°C. It retains its strength up to 537°C. Additions of some elements can rise this point to 650°C. By way of comparison, the strength of magnesium and aluminium alloys sharply drops off at about 315°C. This property of titanium is very valuable in high-speed planes where the heat barrier, that is, the heating of the aircraft surfaces by the friction of the air, becomes much of a problem. This problem assumes truly formidable proportions for re-entrant space probes and spacecraft. If you happen to visit the Soviet Union, you can see the nose cones of several space probes at the U.S.S.R. Economic Exhibition in Moscow. They still bear the traces of the same searing heavenly heat which is given up by meteorites on clear nights.

Titanium has remarkable resistance to corrosion. You may leave a strip of titanium outdoors for years, exposed to rains, mud, frosts, and thaws. Yet it will show no traces of corrosion after this exposure. An iron strip would be covered by a crust of rust or would rust throughout. Titanium retains this resistance to corrosion up to 400-450°C or even higher, if alloyed

with chromium, aluminium or silicon. In resistance to corrosion titanium is superior to stainless chromium-nickel steels. Even seawater, so dreadful to many metals, does not attack it. Nor can many acids, including the all-devouring aqua regia. Because of this, titanium holds out special promise to sea and river craft, the chemical and food-processing industries. It is not at all unlikely that before long the hulls of sea-going tankers and liners will be built of titanium.

Will it pay to replace the cheaper materials with the yet costly titanium? In some cases, yes. Here is one example. A chemical reactor using hot nitric acid had a stirrer made of stainless steel. Even the stainless steel found it very difficult to resist the attack of the acid backed by high temperature. So every few months the stirrer had to be replaced. Because of this the whole production cycle had to be stopped, and this cost ten times as much as the acid-eaten part. Finally the stirrer was made of titanium. Its cost was three times that of a steel one, but it remained in service for five years. It's simple arithmetic to calculate the payoff of the replacement.

Similarly, the digester components made of stainless steel have to be replaced every few hours, while those made of titanium remain in service for years. The cast-iron diffusors of steam-jet ejectors are replaced every three months, and those made of titanium need not be replaced for years.

Titanium is superior to iron, that king of metals, in all respects. As soon as scientists had learned this, its production began to expand rapidly. The first grams of titanium were prepared in 1910. In 1947 the United States made the first two tons of the metal. By 1951 titanium production reached 500 tons a year, and in 1956 it approached 40,000. In 1960 the United States produced about 350,000 tons of titanium.

The history of metallurgy knows cases when the growing demand for a metal brought about as rapid an increase in its production. This happened, for example, to aluminium. At the time of our grandmothers, jewellers used to make brooches from aluminium. Today aluminium goes to make mass-produced furniture. But not a single metal has ever undergone an expansion as titanium has.

And this is happening while our knowledge of its properties is still limited. There is much to be learned about it yet. This is why scientists in numerous laboratories are busy investigating titanium. They are tearing, bending, heating, freezing, fusing, welding, and testing titanium in a multitude of ways, including radio-frequency current and ultrasound. They are eager to come to know the newcomer as thoroughly as they know iron.

They are discovering many intriguing things. Thus, alloyed with tungsten, aluminium, beryllium or boron, titanium shows a rate of creep which is one-twenty-fifth to one-fortieth of that of the unalloyed metal. Even minute quantities of nitrogen, oxygen or hydrogen increase its strength but

reduce its ductility. The greatest promise to the engineer is held out by titanium-aluminium alloys. And so on, and so forth.

Titanium has a bright future before it. This opinion comes from knowledge of its remarkable properties, its abundance, and the occurrence of rich titanium-bearing ores.

Titanium is still costly to make, but it is becoming ever cheaper. Between 1955 and 1958 its price on the world market halved.

OTHER JOBS

We've only mentioned titanium's principal job as a structural metal for chemical equipment, supersonic planes and space probes. But these are newer uses for the metal. Before them, it worked in other capacities in which it is being, and will remain to be, used, whatever its successes in other fields. Perhaps, those are modest jobs, but they are vital to man.

The first use to which titanium was put was in the form of titanium dioxide as a white pigment in paints. Titanium white still remains the best paint of all.

Titanium oxides are used in refractory glass, phosphors, as catalysts for synthetic rubbers, and many other fields. Anhydrous titanium tetrachloride is used in sky writing for advertising and in producing smoke screens. It also serves as a catalyst in many organic reactions.

We can hardly fail to mention tungsten carbide, the hardest of all materials. With nickel or cobalt as the binder, it is used to make heat-resisting parts. It is mixed with tungsten carbide in some of the sintered-carbide cutting tools.

Barium titanate serves as the transducer in echo-sounding equipment and ultrasonic devices.

The great affinity of titanium for oxygen is utilized to deoxidize steel. Along with the oxygen, titanium also removes nitrogen, because at high temperature they combine readily. At the same time, the presence of titanium improves the quality of the steel. Titanium, a major metal of tomorrow, is also a vitamin for the major metal of today.

Thus, it will not be wrong to say that in the future titanium will be used on an ever greater scale both as a structural metal and in other applications.

9

NUCLEAR FUELS
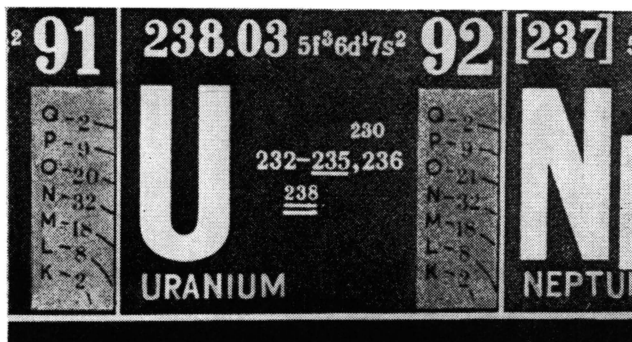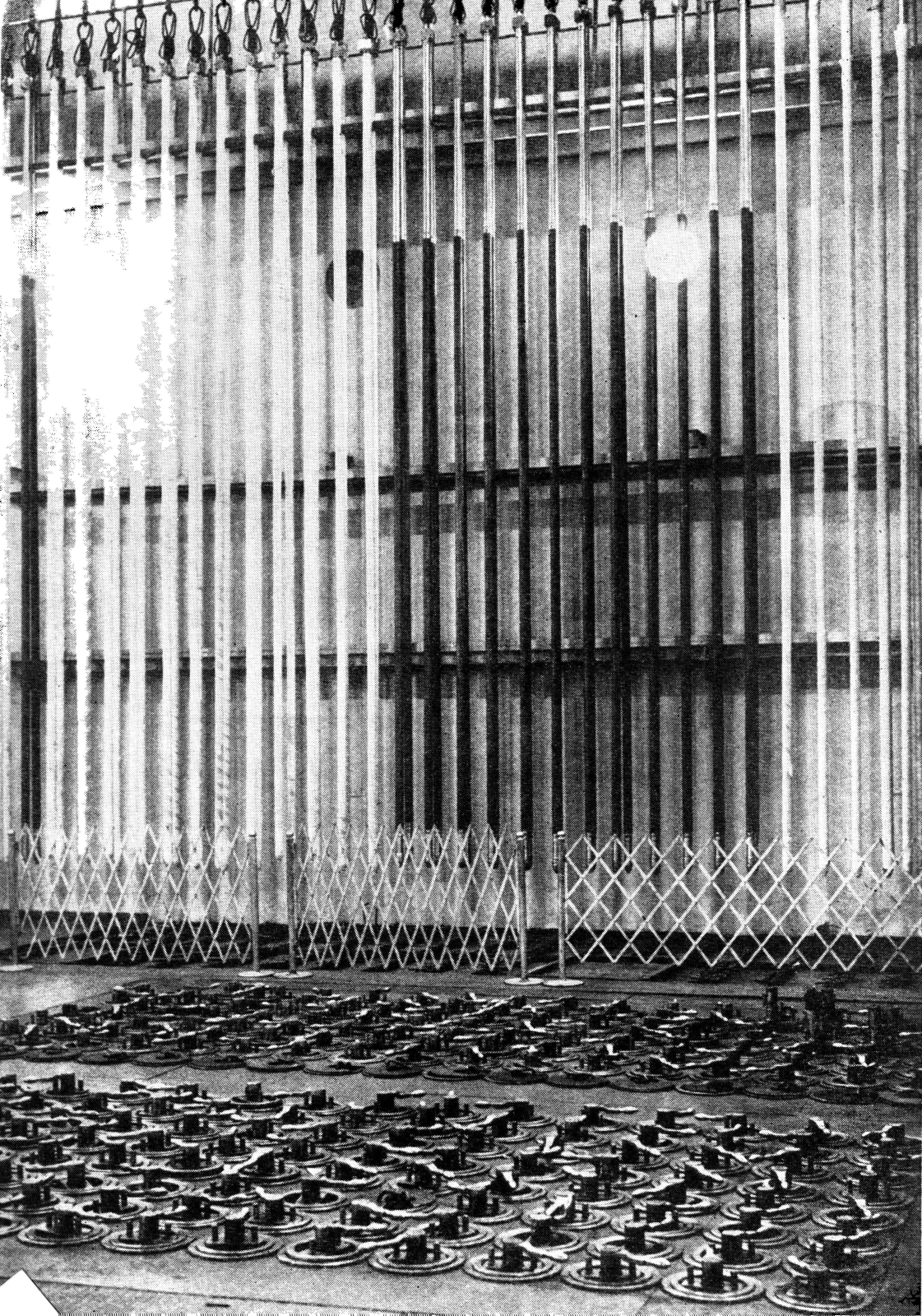
T he great Mendeleyev saw a bright future for the closing element of his Periodic System. He wrote, "I'm convinced that the study of uranium, starting at its natural sources, will lead us to many new discoveries, and do not hesitate to recommend those who are seeking material for new investigations to place special emphasis on its compounds."

His statement was published in 1872. Already in 1896 his prediction came true, for in February of the same year the French physicist Henrie Becquerel reported to the French Academy of Sciences about what was later termed radioactivity. He had wrapped a photographic plate with two sheets of very dense black paper and placed some uranium or potassium bisulphite on it. After development, the plate showed an outline of the bisulphite.

That was the dawn of nuclear power. But scientists still were to do much before the dawn could grow into broad daylight.

Becquerel's work was carried on by Professor and Mme. Pierre Curie. After a good deal of effort Mme. Curie isolated a few grains of radium, the element which seemed the most miraculous of all at that time. She devoted the rest of her life to the study of radium and died of what was called radiation illness much later.

Visitors to a world fair could see Mme. Curie's laboratory records. When they brought a Geiger counter to the sheets of paper yellow from age, the instrument would go clicking and crackling, as it counted streams of elementary particles. They were coming from the specks of radioactive dust left on the paper by the slim fingers of the woman scientist who had sorted out tons of uranium ore.

Uranium and radium were regarded as the exotic whims of nature until the late 1930's, when discoveries in nuclear physics made the generation of power by nuclear fission more than a theoretical possibility.

THE NAMESAKE OF THE SEVENTH PLANET

In 1781 William Herschel, a German-born musician who had settled in England, noticed a luminous cloud in his home-built telescope. At first he took it for a comet. Further observations, however, convinced him that it was a seventh planet. Herschel called it Uranus, in honour of the most ancient of the Greek gods and the first ruler of the Universe, who personified the sky to the Greeks.

Herschel's discovery won him the title "sir", election as a fellow to the Royal Society, and appointment, the next year, as Royal Astronomer to King George III.

By the same token Klaproth gave the name "uranium" to the unusual new substance he had found in pitchblende ores. Actually, as often happened in his time, what he had isolated was an "earth", or oxide of uranium. Metallic uranium was first prepared by E. Peligo of France in 1841, by reduction with metallic potassium.

At first glance uranium does not seem attractive in its properties, mechanical or chemical. It is very heavy. Its specific gravity is 19.05, or twice that of lead. It is rather soft, malleable and ductile. When heated, it can be forged, drawn and extruded. In fact, it is worked into tubing, wire and foil this way.

In appearance uranium resembles steel. When just polished, it presents a silvery surface with a bluish tinge. After several hours' exposure to air, however, it tarnishes. The powdered metal burns brilliantly when heated to 170°C and can self-ignite if dispersed in dry air. Immersed in water, uranium slowly decomposes it. All this is a sign of moderate chemical reactivity.

The commercial uses of uranium before the discovery of fission were limited. It had never been tried as a structural metal, in filaments of electric lamps or as an additive to special steels. Compounds of uranium had found some use in photography and dyeing and as ceramic and glass colouring agents. If it were not its special properties, uranium would have remained

an obscure, useless metal, the last in the Periodic System, included in university collections simply "just in case".

And these properties have proved astonishing indeed. Uranium unceasingly gives up radioactive particles. As it does so, its nuclei change into other elements. These changes go on unabated, whatever the substance containing uranium, or whatever the temperature or state, liquid, solid or gaseous, in which it exists.

This radioactive disintegration, as it is called, ends up in the production of lead. True, it takes much time for the process to come to completion. One gram of uranium contains 2.5×10^{21} atoms. About 12,000 atoms out of this number break up every second, which works out to nearly 5,000 million years for half the number of the atoms to disintegrate. During the next 5,000 million years only a half of the remaining half will break up, and so on. This is termed the half-life period.

This break-up is accompanied by the evolution of huge amounts of energy. On disintegrating, one kilogram of uranium generates so much energy that it would be enough for a locomotive to run round the globe via both poles.

It is these possibilities of generating power that have made uranium a vital metal of our times.

ATOMIC NUCLEI AS A FUEL

Any fuel is above all graded on the basis of the heat it can give up on burning. In this respect nuclear fuel is unexcelled. One kilogram of petroleum generates an equivalent of 11.6 kilowatt-hours of heat on complete combustion. One kilogram of uranium generates 22,900 thousand kilowatt-hours!

A 600-MV thermal power plant burns five trainloads of coal every day. A nuclear power plant of the same capacity uses about one ton of uranium for a year's operation. These are truly uncomparable quantities!

Why is it then that nuclear power plants have not become the sole type used for power generation? Why are we still wasting time and effort, extracting coal and petroleum and building expensive and awkward thermal-power plants?

Is this because nuclear fuels, uranium and thorium, are rare elements? One might think so, because a mere two decades ago only a few of the best laboratories in the world had test-tubes with greyish pieces of uranium at the bottom, and very few physicists had ever held these unusually heavy grains of the metal in their hands.

Yet uranium is not a rare element. It accounts for 0.0005 per cent of the Earth's crust by weight, or for about as much as lead. And is lead a

U_{235}
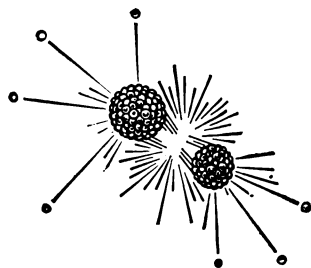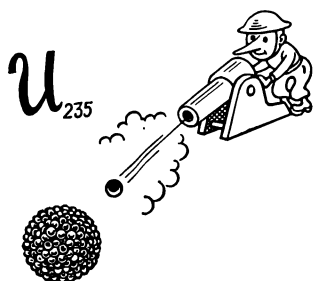
That's how a chain reaction is set off

rare metal? Bismuth, silver, gold and platinum are less abundant by comparison.

Thorium, another nuclear fuel, is half again as abundant as uranium, accounting for 0.0008 per cent of the Earth's crust by weight.

The trouble is that concentrated deposits of uranium are very rare. As a rule uranium is only present as an accessory element in other ores. Nor is it an easy task to process the ore. Uranium ore, for example, is crushed, ground, concentrated, repeatedly leached, and precipitated. The precipitate is then either reduced to metallic form or converted to the gaseous uranium hexafluoride.

But uranium is poisonous, a feature which complicates its production still more. Constant watch has to be kept on uranium dust and fumes, lest they should contaminate the surrounding air. Some of the chemicals used to dissolve uranium compounds are either poisonous or inflammable. This is why uranium factories have sophisticated fire-fighting and ventilating systems. Then, again, when uranium metal is obtained—as little as seven parts from ten thousand parts of ore—you're only half the way through converting the yellowish-green stones of uranium ore to nuclear fuel. This is because the metal contains only seven parts in a thousand of what can be used as a nuclear fuel direct. For natural uranium consists of three isotopes, uranium-238, uranium-235 and uranium-234. Of the three only uranium-235 is a nuclear fuel, and it has to be isolated from the other two.

Unfortunately, chemical methods of separation are useless. There is no solvent which would dissolve uranium-238 while leaving uranium-235 as a solid residue. Nor is there a reagent which would combine with uranium-235 while leaving uranium-238 intact. Both isotopes, like any isotopes, are absolute twins, chemically speaking. The only difference between them is in mass, something about more than one per cent. But this is the only thing which can be used for separating the isotopes.

Physicists have many ways of separating substances differing in weight. The simplest is the well-known cream separator. You pour whole milk into

it at the top. The milk passes through a number of spinning cups. The cream being lighter goes down through a hole in the bottom of each cup. The bluish watery part is thrown off at the edge of the cup and pours out of a different pipe than the cream.

This and other methods of separation are only applicable to gases, liquids and loose solids. Metallic uranium cannot be reduced to powder with grains the size of a single atom. In laboratories the uranium isotopes are separated, using uranium hexafluoride and not metal uranium.

Under normal conditions uranium hexafluoride is a solid. It volatilizes at a relatively low temperature, and its fumes can be treated in a centrifuge or a system of centrifuges so as to separate it into the constituent isotopes.

Commercially, however, use is made of a different method, known as gaseous diffusion. The centrifuge technique would be prohibitively expensive for large-scale production.

At a gas-diffusion works, the diffusion chambers occupy a large area of many acres. They stand closely one to another, separated only by barriers of a finely porous material. Through these barriers, or filters, uranium hexafluoride travels from chamber to chamber. The lighter molecules containing uranium-235 travel faster than those with uranium-238. This is the basis of gas diffusion. Naturally, since the difference between the isotopes in mass is small, the difference in rate of diffusion is likewise small. Because of this, the diffusion operation has to be repeated several thousand times before the final uranium hexafluoride is practically free from uranium-238.

The operation involves the consumption of large amounts of electricity, heat and water, and the cost of the separation is therefore very high.

Other grades of nuclear fuel, plutonium and uranium-233, are still more difficult to obtain. Plutonium is produced by irradiating uranium-238 in a nuclear reactor; uranium-233 is got by a similar procedure from thorium.

Those are the reasons why today nuclear power is still more costly than electricity generated by hydraulic or thermal stations.

Is this to mean that nuclear power has no future for man and that nuclear power plants will never be able to compete successfully in cost with hydroelectric stations?

Nothing of the kind! For one thing, nuclear fuel will become cheaper and cheaper to prepare. For another, the possibility exists, by using suitable types of reactors, of converting all of natural uranium and thorium into nuclear fuels instead of depending solely on the rare isotope uranium-235. This will have the effect of multiplying some hundred-fold the world's total nuclear power resources. In a way, it looks like producing more and more fuel by burning it. This paradoxical process or arrangement has been given the name "breeding", and the reactors operating on this principle are known as breeder reactors.

As scientists have calculated, breeding and breeder reactors will be able to meet mankind's requirements in electricity in about thirty years from now.

Today the atomic energy industry is developing in big strides. In 1954 the Soviet Academy of Sciences commissioned its first 5-MW nuclear power plant. In December, 1957 the Soviet Union launched its first nuclear-powered 44,000-hp ice-breaker *Lenin*. Since then many countries have built their nuclear power plants and atom-propelled ships.

THE UBIQUITOUS ATOM

The supplies of uranium on the Earth are large enough to meet the world's requirement in energy. Here is a proof.

According to economists, some 84,000,000 million kilowatt-hours of electricity will be generated in the world in the year 2000. This would require either 15,000 million tons of coal or 4,000 tons of uranium. At the present time much more uranium is being extracted. In 1956 the world outside the socialist countries produced about 13,000 tons of uranium oxides. In 1959 the production increased to 39,000, or three-fold.

Uranium is found practically everywhere. As the Soviet scientist Vernadsky wrote in 1934, uranium "turns up everywhere around us. It is scattered not only in rocks, but also in all minerals."

The heat given up by uranium due to nuclear decay is one of the principal sources of thermal energy inside our planet. Over 42 per cent of the total heat due to nuclear decay comes from uranium, about 45 per cent from thorium, and close on 12 per cent from potassium. This is an amazing amount of heat.

What is still more amazing is that if the Earth contained as much of the radioactive elements in its insides as it does in the crust, one hundred times more heat would be generated. The Earth would have an altogether different climate and would be hardly suitable for man to live on. In all probability, it would be a molten sphere like the Sun, only much smaller in size.

This is not so, however. The insides of the planet do not contain radioactive elements. Only the Earth's crust is rich in them, including uranium.

Why this happened so is anyone's guess yet. But scientists are looking for an answer. It may turn out that the radioactive elements found their way onto the Earth after all the other elements, when the planet was passing through some dust cloud which settled to form the planet's crust. Or an explosion on the Sun a long, long way back splashed our planet with substances containing uranium and thorium. Or some other cause existed.

Incidentally, the uranium content in the crust gives a clue as to the "date of birth" of the Earth's top layers.

As said earlier, uranium never stops breaking up, until it eventually

decays into the stable element lead. If we take a specimen of some uranium-bearing rock and determine its uranium and lead contents, their ratio will give the age of formation of that rock. Using such techniques, it has been established that the age of the Earth's crust is between 3,000 million and 5,000 million years.

Other radioactive elements, such as radiocarbon, argon, or potassium, can also be used for this sort of age determination, or dating, of rocks, minerals, and organic remains.

BETWEEN URANIUM AND LEAD

When scientists had traced the entire chain of decay from uranium to lead, they found that almost all the elements between the two were the intermediate products of this decay.

The first step from uranium towards lead is protactinium. It is found in nature only because its supply is continually replenished by the decay of uranium. It breaks up with a half-life of about 34,000 years and would not have been discovered otherwise.

It was discovered by F. Soddy and J.A. Cranston of England in 1913 and independently by O. Hahn and L. Meitner of Germany in 1918. Metallic protactinium, as should be expected, is extracted from uranium ores. Protactinium metal was first prepared in 1934. It is silvery white and is not attacked by air. That's about all we know about it today.

The next step is thorium. It is not an accidental, short-lived element in the Periodic Table. Its half-life is 13,900 million years. Hardly one-third of this period has passed since the Earth's crust was formed.

Thorium is fairly common in the Earth's crust. In any case, it is not a rarity. It even has a mineral of its own, monazite, occurring as sand in India, Brazil and the United States.

Thorium was discovered by J. J. Berzelius in 1828 in a mineral (later named thorite) from Brevig, Norway. He named it after Thor, the Scandinavian god of war. The metal resembles nickel in colour. It melts at 1700°C and boils at 5200°C. Its specific gravity is 11.5, and it is the second heaviest of the naturally occurring elements. Being soft as lead, it can be rolled to sheet, drawn to wire and pressed to odd shapes while cold.

The massive metal is stable in air, though it turns grey on the surface. When heated in air, it takes fire, burning with a dazzling, white flame. On reacting with hydrogen, it can absorb many times its volume of that gas.

Until quite recently the most important use for thorium has been the Welsbach mantle for gas lighters. On burning, town gas produces a dull flame, even less bright than that of a kerosene lamp. With a Welsbach mantle

put on, the gas lighter gives up a brilliant white flame. The mantle is made of woven fabric (long fibre cotton, ramie, or artificial silk) treated with cerium and thorium oxide. At one time almost all of the thorium production was used for this purpose.

Today thorium oxide has come into another important use. It is applied to the cathodes of some electronic valves. When the filament is heated, the thorium oxide readily sheds its electrons, the very electrons which do all the jobs in the valve. In metallic form, it is used in making targets for X-ray tubes. One of its more recent applications is as an alloying addition to magnesium to produce lightweight but strong alloys which retain their structural properties up to 400°C. One such alloy contains 1.5 to 2.5 per cent thorium, a little manganese, and the remainder magnesium. It is used in the construction of aircraft and guided missiles. It is one-third lighter than aluminium alloys.

All of its uses, however, are overshadowed by its service as a nuclear fuel. As a rule, thorium is alloyed with the radioisotopes of other metals for this purpose. As some scientists believe, thorium is to play a part in atomic energy comparable with that of uranium.

Moving one step further to the left brings us to actinium. Like protactinium, it owes its existence to uranium decay. It was originally obtained by Debjern from uranium ore in 1899. That's about all we can say about this ephemeral element.

When their work was drawing to an end and it was clear that before long they would get the new metal in pure form, Pierre Curie told his wife and colleague, Mme. Curie, "I wonder what it will be like. I wish it were attractive."

The metal was radium, discovered through self-sacrifice and rare persistence. It surpassed all of their expectations. At first it seemed a miracle. It looked as if the energy it was giving up all the time came from nothing. In a tightly sealed test-tube new elements would come into being—from nothing! For it was not easy to guess at once that radium was changing to radon and lead. No one had ever seen that happen. Some came to question the validity of the law of conservation of energy and matter. The very foundation of all physics seemed to shatter.

Before long, however, scientists learned what was what. The great Einstein related mass to energy. The time had come for the practical utilization of the new metal.

In the meantime, Mme. Curie and Debjern prepared pure radium by electrolysis. "Radium" proved an appropriate name for the new metal. Radium is silvery white, rather light in weight (its specific gravity is about 6), mel-

ting at 960°C and boiling at 1140°C. It is highly reactive. It is attacked by air and produces a black film of oxide on the surface. It eagerly combines with carbon and nitrogen, and decomposes water readily. It can be kept pure only in a vacuum, protected from any temptation to react.

Radium salts are luminous, and this property was the first to be utilized by man. Well before the discovery of radium it had been known that powdered zinc sulphide, suitably prepared and mixed with small amounts of pigments, gives off light in the dark. However, the paint loses its luminosity rapidly. From time to time it has to be exposed to bright light for "charging". And this is not always possible. But the paint will remain luminous practically for ever, if a minute proportion of radium has been added to it. As little as a few parts radium in a million parts phosphorescent zinc sulphide will be enough. Then the compass on a ship wintering in the Arctic Ocean will remain visible throughout the night lasting many weeks, and the instruments on the dashboard of a plane on a "blind" flight will serve its pilot dutifully. You can prepare luminous paper on which an experimenter can jot down his observations in complete darkness.

Then followed the use of radium in medicine. The gamma rays from radium proved extremely effective (in the proper dose, of course) in the treatment of many diseases, including the formidable and implacable cancer and lupus, tuberculosis of the skin.

And, of course, radium was at one time in great demand for research purposes. Scientists saw in it a key to the enigma of matter.

Today man has learned how to dispense with radium in all of these applications. In medicine use is being made of radioactive cobalt, much cheaper and no less effective as a source of gamma rays. New luminous paints have been devised without radium, because even in the smallest amounts it can do harm to man. Scientists have come by far better means of getting insight into the structure of matter than radium. So radium has become the first unemployed among the metals.

Standing next to radium, in the left-hand bottom corner of the Periodic Table, is francium.

In the Periodic System the metallic properties become more pronounced as we move from right to left and from top to bottom. The right-hand top corner of the Table is occupied by the most active non-metals. So francium is the "most metallic" of all metals. Yet it still remains an enigma.

The existence of francium was predicted way back by Mendeleyev as "eka-cesium". It was not until 1939, however, that francium was discovered by Mlle. Marguerite Perey of the Curie Institute in Paris, as a natural isotope resulting from the decay of actinium. She named the new element after her country.

Francium is extremely unstable to radioactive break-up. The longest life of any of the several isotopes of francium is 21 minutes for the 223 isotope. Some break up in a matter of a few hundredths or even thousandths of one second. Naturally, you cannot possibly learn much about the properties of an element decaying almost as fast as it is produced, and then in tracer amounts only. This is why we know but little about its physical properties.

About as much we know its chemical behaviour, except what can be deduced from its position in the Periodic System. What is beyond any doubt is that francium is very active chemically. Like radium, it can only be preserved in a vacuum.

As we move one step on in the series from uranium to lead we run into radon (once called niton, then emanation, and now emanon is proposed), the short-lived direct product of radium decay.

Radon is the heaviest of all the inert gases. It is very dangerous; some of it diffuses from radium salts and lodges its active decay products on surrounding objects, making them radioactive.

Radon is followed by astatine and by polonium.

Polonium was isolated by Mme. Curie even before radium from uranium ore and was named so in honour of her native country. This element, too, is deprived of the right to exist long. The most stable of its isotopes (of which there are nearly twenty) has a half-life of approximately 140 days. But this has proved quite enough for scientists to learn the properties of polonium.

Polonium, too, was predicted by Mendeleyev. But the great chemist believed that the yet-undiscovered element would have two distinct crystal lattices, one above and the other below 75°C. He was unable to foresee that polonium would retain the second lattice at room temperature owing to the heat given up by radioactive break-up. He did not know anything about radioactive disintegration yet.

The specific gravity of polonium is about 9.3. In air it oxidizes rapidly. The radioactive particles given off by polonium break up oxygen, causing it to form ozone, and the latter oxidizes the metal. The time for practical uses, other than in the laboratory, has not yet come for polonium.

Squeezed between polonium on one hand and lead on the other is bismuth. Europeans recognized bismuth as a specific element in the Middle Ages and named it "wismut", which was later latinized to "bisemutum".

Bismuth occurs in the Earth's crust in about the same abundance as silver. However rich bismuth ores are a rarity. The main source of bismuth is a by-product of copper and lead smelting and refining, and the tailings of tungsten ore beneficiation.

There is nothing about bismuth that would set it apart from the other metals for which nature does not seem to have cared much. It will fracture as a brittle, crystalline metal having a high metallic lustre with a pinkish tinge. Its specific gravity is about 9.8. It melts at 271°C and boils at 1560°C, and is not particularly active chemically.

Bismuth has proved a poor companion to steels and some other metals. Its presence makes them brittle and unmalleable. This is why every effort is made in steel manufacture to get rid of as much bismuth as practicable.

Yet bismuth has found quite a number of important uses in alloys with other low-melting elements. Together they form a group commonly called "fusible alloys". These other elements are lead, tin, cadmium, and indium. One such alloy melts at as low as 47°C. In effect, it will melt in a cup of hot tea.

Fusible alloys, such as Wood's or Rose's metal, find use as fusible plugs in automatic fire sprinkler systems and fire door releases. Should the temperature in the location grow dangerously high, the plug fuses, and jets of water put out the fire. Fusible plugs are also used in boilers. Should the temperature of the steam exceed a safe limit, the safety plug fuses, steaming off the pressure and saving the plant.

Another alloy containing one part bismuth and four parts mercury has the remarkable property of adhering to many materials, including glass. The alloy is used in the manufacture of mirrors instead of silver.

Bismuth-rich alloys are also used as solders, especially for joining glass and a metal. Some of them, when cast, make sharply defined castings, pattern letters, ornaments and table-ware. Bismuth is also added to type metals.

Those are quite numerous uses for an ordinary metal like bismuth. To them we should add one more. Bismuth has the unique property of varying its electrical resistance under the action of temperature and the strength of the surrounding magnetic field. This property is utilized in the measurement of magnetic fields. The instrument used for the purpose is called a bismuth spiral.

Man has devised many uses also for the compounds of bismuth, mainly in medicine, cosmetics and glass-making.

Finally we reach lead, the last step in three chains of nuclear transformations starting, respectively, at uranium-238, uranium-235 and thorium. Each chain terminates in a lead isotope of its own. So we can easily tell which chain has produced which lead.

Lead is a heavy, soft and weak metal. You can scratch it with a finger nail. It will melt in a camp-fire, for its melting point is as low as 327°C. It will boil at 1700°C. Its specific gravity is 11.3.

Lead is one of the oldest metals known. It is said to have been in use as early as 4000 B.C. At first it was made into water pipes, roof tiles, vessels and projectiles. With the advent of fire arms, lead became the classical metal of bullets and shot and is still used for this purpose today. Progress in the chemical industry has added many more duties to lead. Its ability to withstand the attack of some acids has come in very useful for the protection of other metals. Many parts of chemical plant at factories manufacturing sulphuric acid are made of either lead or lead-coated metals.

Much of the lead produced today goes to make plates for storage batteries, cables for communications and power-transmission lines. In cables the plasticity of lead is especially valuable; they can be bent to any shape without breaking. Buried underground, cables stand up easily to the attack of any aggressive factors in soil. A good proportion of lead is manufactured in alloy form.

' Lead has proved one of the most "opaque" materials to nuclear radiations. Because of this, so-called biological shields in nuclear work are often made of lead. The cobalt guns used to treat cancer have their Co-60 source enclosed in a substantial pear-shaped block of lead. The operators of X-ray units usually wear lead aprons.

The jobs lead is doing are all very important and vital to man. This is why its production is growing all the time. In 1952 the world outside the socialist countries produced 1,600,000 tons of lead. In 1958 the figure rose to 1,930,000. For all fluctuations, there has been no sign of decline in the manufacture of this working horse of a metal.

ALCHEMISTS' DREAM COMES TRUE

As one outstanding American physicist has remarked, the best known of all elements today is probably plutonium. Yet nothing had been known about it until 1940 when a few atoms of this element were obtained.

If the reader took his chemistry course before the war, he would recall that the Periodic Table in his chemistry text stopped at uranium.

I bet many thought of extending the system, both schoolboys and grey-haired scientists, at that time. Now and then scientific journals would report the discovery of element 93, only to refute it or be refuted soon afterwards.

Scientists are not any better off today as far as naturally occurring transuranium elements are concerned. Of the entire series known at the present time only the first two, neptunium and plutonium, have been found in tracer amounts in uranium ores. It is possible in principle that the ores of the rare-earth elements contain some curium, the fourth transuranium element. Its half-life is long enough for scientists to hope to find its rare atoms by the present-day highly precise techniques of analysis.

But this would be hardly needed. Scientists were looking for the naturally occurring neptunium and plutonium when they did not know how to prepare them artificially. Today plutonium is prepared artificially by the kilogram. It is made much as cheese is produced at dairies, plastics at a chemical factory, or fabrics at textile mills. Scientists have learned how to materialize the dream of medieval alchemists about transmuting base metals to gold. Instead of expensive, but useless gold, however, people in white frocks are making plutonium, a far more valuable metal.

The first breakthrough in this art dates back to 1934 when the famous Italian physicist Enrico Fermi bombarded uranium with neutrons. When he analyzed the uranium target, Fermi found a new element in it. Unfortunately he could not place it in the Periodic Table, though he presumed it was a transuranium element.

The first of the transuranium elements to be produced synthetically was neptunium, so called after the planet Neptune which follows the planet Uranus in the sky. The isotope Np-239, with a half-life of only 2.35 days, was produced by McMillan and Abelson in 1940 at Berkeley, California, as the result of the bombardment of uranium with cyclotron-produced neutrons.

In 1940, Seaborg, McMillan, Kennedy and Wahl at Berkeley produced plutonium, the second transuranium element, so called after the planet Pluto. It was prepared by deuteron bombardment of uranium in a cyclotron.

The year 1944 saw the discovery of two more transuranium elements. Since there were no more planets after which to call them, the new elements were named americium after the Americas and curium after Pierre and Marie Curie. Americium was identified by Seaborg, James, Morgan and Ghiorso; and curium by Seaborg, James and Ghiorso. Although curium comes after americium in the Periodic Table, it was known before americium and was the third transuranium element to be discovered.

Today these four elements are obtainable in pure form and in sizeable quantities. This is particularly true of plutonium which can be easily obtained in large amounts in nuclear reactors from natural uranium. Today it holds the dominant position as an explosive ingredient in nuclear weapons, and as a key material in the development of industrial utilization of nuclear energy.

In 1949 Thompson, Ghiorso and Seaborg synthesized the fifth transuranium element. They called it berkelium, after Berkeley, California. In 1950, the same team in collaboration with Street discovered the sixth transuranium element, californium, thus named after the state and University of California.

Late in 1952 the seventh transuranium element, named einsteinium after Albert Einstein, was identified in the debris from a thermonuclear explosion by Ghiorso and co-workers. The same team also identified the eighth

transuranium element, called fermium after Enrico Fermi, early in 1953, likewise in the debris from a thermonuclear explosion. Later on, these elements were prepared by other methods.

In May 1955 followed the discovery, by Ghiorso, Harvey, Choppin, Thompson and Seaborg, of the ninth transuranium element. That was element 101 of the Periodic Table. The investigators called it mendelevium, in recognition of the leading part played by the great Russian chemist in the prediction of the yet undiscovered elements.

In 1957 word came from Stockholm about the discovery of element 102. The new element was named nobelium after Alfred Nobel in recognition of his services to science. But the team of American, British and Swedish physicists who sent out the report were soon proved wrong. Repeat experiments at Berkeley and in the Soviet Union failed to confirm their discovery. It was not until the next year that a team of researchers at Berkeley identified element 102 of mass number 254, using a different technique than their colleagues at Stockholm. Similar results were obtained by Flerov and co-workers in the Soviet Union. But although the name "nobelium" holds no longer, a new name has not been suggested yet.

In the spring of 1961 a report was published about the discovery of element 103. Its discoverers Ghiorso, Sickeland, Larsh and Latimer have named it lawrencium, in honour of Ernest O. Lawrence, the inventor of the cyclotron, the founder and head of the Radiation Laboratory at Berkeley, California.

As more transuranium elements were discovered, evidence was piling up showing a striking chemical similarity between them. Moreover, they have been found to bear a chemical resemblance to another group of elements, the rare earths (atomic numbers 57 through 71). Thus, we've come by a second rare-earth, or rather a rare-earth-like, series. In addition to the transuranium elements it embraces uranium and actinium. The reader certainly knows that all the rare-earth elements are placed in a single square in the Table, belonging to lanthanum, and another name for them is, therefore, the lanthanides. A similar thing has happened to the rare-earth-like series. Because of their chemical similarity they have all been identified with actinium and given the name "actinides".

The actinides are typical metals. The heaviest among them is neptunium with a specific gravity of over 19. It melts at about 640°C. The most stable of its isotopes, Np-237, has a half-life of 2,200,000 years. It is currently obtained in gram quantities as a by-product from nuclear reactors. This is more than the production of radium a mere twenty-five years ago.

Plutonium metal has a bluish tinge and quickly tarnishes in air. It melts at about the same temperature as neptunium, but differs from it in

other properties. To begin with, it has an isotope with a half-life of over 75 million years. It is the only metal existing in six crystalline modifications at atmospheric pressure in the range from room temperature to melting point. To put it differently, its lattice changes six times as the metal is heated from room temperature to melting. At the same time, it changes in both volume and density, for which reason its specific gravity varies from 16 to 20 in the same temperature range.

At room temperature plutonium has the highest electrical resistance of all metals. While on heating all metals expand, plutonium contracts. If plutonium were not strongly radioactive, its peculiar physical properties might have had many uses in industry.

Commercial production of plutonium is regarded as a simple process. It is produced in nuclear radiators from natural uranium in kilogram quantities. Each kilogram of the source U-235 yields 800 grams of plutonium.

The most stable isotope of americium, Am-243, has a half-life of 7,950 years, that of curium 470,000 years, that of berkelium 7,000 years, that of californium 800 years, and that of einsteinium under one year. Fermium decays completely in a few days, mendelevium in about a half-hour, and nobelium in a few minutes.

In 1964 a Soviet team under Flerov at the Joint Nuclear Research Institute in Dubna reported the discovery of element 104. They got it as the result of heavy-ion bombardment in the world's biggest cyclotron. The investigators obtained 150 atoms of the new element which has a half-life of only 0.3 second. In June 1966 it was named kurchatovium in honour of the late Igor Kurchatov, the top nuclear physicist of the Soviet Union.

But there are more important things about the new element than the number of atoms caught or its half-life. It sharply differs from the other man-made transuranium elements. Chemically, kurchatovium is the analogue of hafnium (element 72) and is not an actinide (see the Periodic Table at the beginning of the book). Thus, it has ushered in a series of trans-actinide elements. With its discovery, far-reaching forecasts can be made about other trans-actinide elements. When scientists discover element 106, it will probably be the analogue of tungsten, but heavier and more refractory.

The actinides and kurchatovium are not the only man-made elements. In addition to francium, physicists have prepared several other missing elements in their laboratories. These are elements 43, 61 and 85, named technetium, promethium and astatine.

Technetium, predicted already by Mendeleyev, was prepared by the Italian scientists Segre and Perrie in 1937. It was the first element to be

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produced artificially, for which reason it was named "technetium" (from the Greek "tekhnetos" for artificial). Today it is obtained in fairly large quantities. The nuclear fragments produced by one kilogram of plutonium contain about 10 grams of long-lived isotopes of technetium. Of all its properties the most interesting is that it becomes a superconductor already at 11.2°K, the highest temperature of all metals.

The discovery of promethium has been claimed at least three times, but the official discovery of the element was completed by Coryell and co-workers in 1946. In 1947 his group proposed the name promethium from the Greek god Prometheus, the fire-giver, and the International Congress at Amsterdam adopted it in September, 1949.

Well before its actual discovery, astatine was called eka-iodine. Then it was variously called "alabamine", "dakin", and "helvetium", as its investigators thought it appropriate. Finally, early in 1940 Corson, MacKenzie and Segre reported the discovery of a substance which gave up nuclear radiations. Their findings were confirmed, and in 1947 they suggested that their element be named "astatine" (from a Greek word meaning "unstable").

So much for the discovery of new, synthetic elements. What about their commercial use on a large scale?

Well, this point is as much any one's guess as the destiny of a newborn baby. It is not at all unlikely, however, that they will become as common as, say, vanadium or antimony are today.

The present-day Periodic Table has no vacant places left in the middle. Man has discovered all the elements there are to discover except—except those lying on either side of the Table. Ahead of hydrogen, which opens the System, the Soviet scientist Roguinsky has placed the neutron as element O. It may well happen that the Table will some time be extended beyond element O, into the realm of anti-matter.

At the other end, past kurchatovium, we may find stable elements which do not decay as the actinides do.

This will be proved or disproved before long. Physics, which has been advancing at a breakneck rate recently, will furnish exhaustive answers soon.

But this is not to mean that new problems will not arise.

10

THE ETERNAL METALS
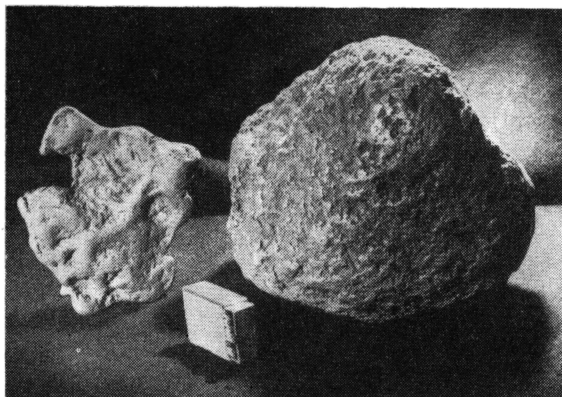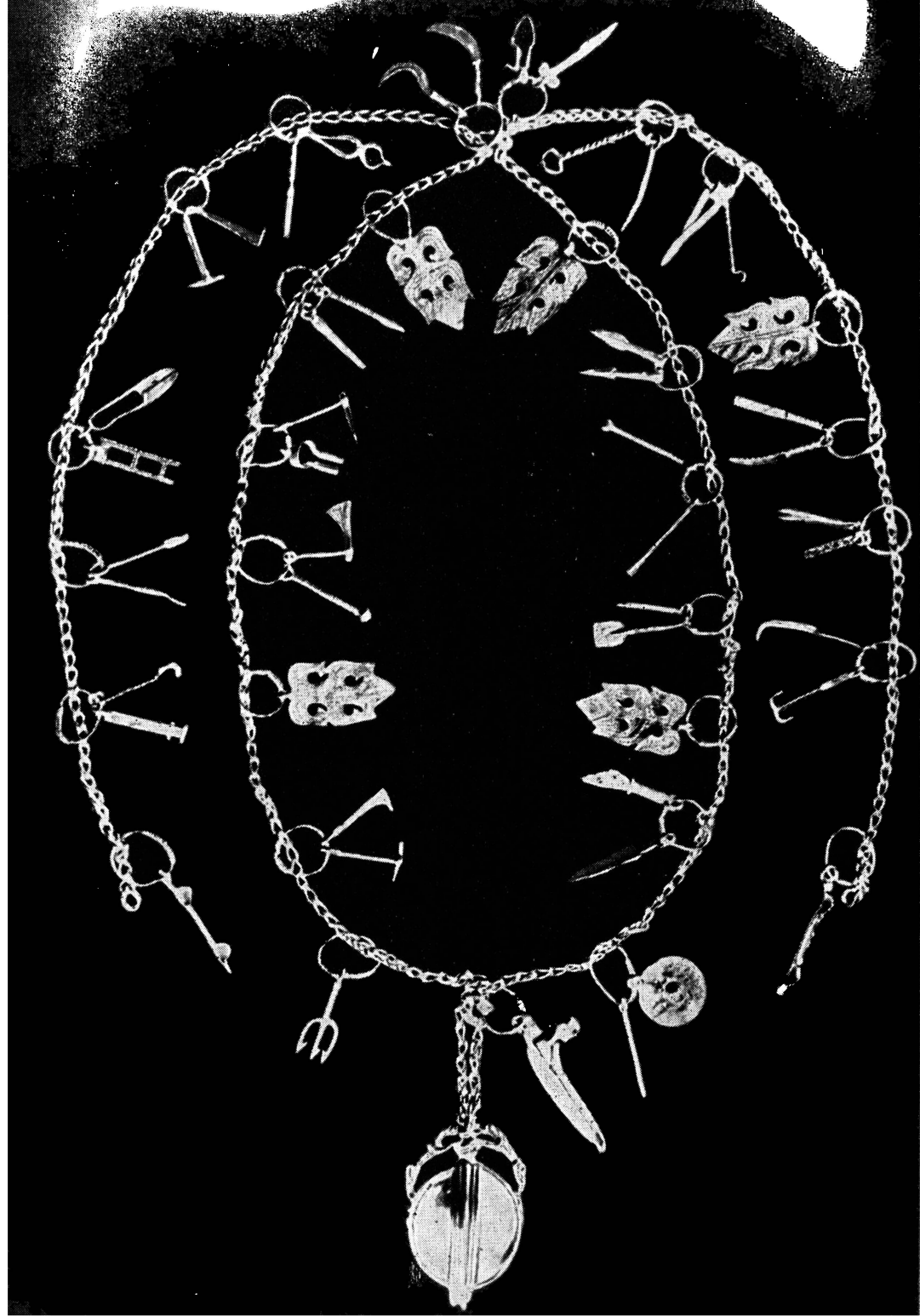
For centuries gold has been made into jewelry and coins. For centuries all that man creates "in the sweat of his brow" has been valued in terms of gold, and all merchandise has had its price in so much gold. This was so in ancient China, India, Egypt and Greece. This is so in our modern world.

Throughout its history gold has had other metals do all jobs for it. Except in jewelry, false teeth, gold facings, sometimes electrical contacts and spinnerets in the manufacture of man-made fibre, it has no other "workaday" uses. This is not to mean, however, that with time man will not find more applications for gold.

Sharing company with gold are several other metals, its neighbours in the Periodic System. These are silver which has been a monetary standard side by side with gold and was valued more than gold in ancient times; platinum which even today is valued more than gold; and the platinum metals palladium, iridium, rhodium, ruthenium and osmium which are less abundant than gold and have come to serve man only recently. All of these metals have many vital uses.

Pushkin has the Greedy Knight in his poem of the same title say:

> Yes! If all the tears and blood and sweat
> That were the price for all here kept
> Would rise up from the bowels of the earth,
> The Deluge would be repeated.—Drowned I'd be
> In my cellars full of Treasure...

For centuries gold, that eternal glittering metal, has brought in its wake crimes and wars, poverty to the majority and senseless luxury to the few. Already in ancient tales and legends gold is depicted as the seed of the basest passions. Wars and plots for the possession of gold are described in many Egyptian papyri dating back thousands of years. It was because of gold that the Spaniards destroyed the unique civilizations of the Aztecs and Mayas. Whole nations were wiped off the face of the Earth so that Spanish, Portuguese and British conquerors could bring ship-loads of gold back home.

The discovery of every new gold deposit would give rise to another "gold rush", a mass psychosis accompanied by countless tragedies, deaths and crimes. This was so when gold was discovered in Brazil. The same thing happened when crowds of gold-diggers swarmed upon steaming-hot California. Jack London gave a masterly description of the gold rush on the banks of the icy Klondyke.

A good many wars in man's history have been provoked by gold. There was a war between England and Spain for the gold of America; there was a war between England and Transvaal for the gold and diamonds of South Africa. Indeed, all feudal and capitalist wars have been for gold, whatever the nobler causes, religious or nationalistic, that were avowed.

To date over 50,000 tons of this noble metal has been mined in the world. The greater part is probably kept in the safes and vaults of the world's banks.

But gold also has a brighter side to it. It has been made into a host of exquisite things by the skilful hands of jewellers. Unfortunately, their masterpieces were often turned to scrap only because they were of gold.

Man began to mine gold at the same time as or, perhaps, earlier than copper. Says Karl Marx, "Gold was in fact the first metal to be discovered by man." For native gold need not be smelted or refined. This is why we run into man-worked gold in the artefacts dating from the late Neolithic period. Plato mentions gold among the metals in which Atlantis was rich.

However, gold was scarce in man's ancient world—Europe, North Africa and South Asia. So about the same amount of gold was circulating among people. The balance was upset by the discovery of the Americas. The price of gold took a nose-dive.

The expansion in gold production was particularly big towards the end of the 17th century, when large-scale development of the goldfields in Brazil began. During the 18th century the yearly production of gold averaged about 19 tons. The beginning of the 19th century was occupied by the war the North American colonies fought against Spain, and the production of gold sharply decreased. The yearly average between 1801 and 1820 was only 14.6 tons. But in the mid-19th century annual gold output rose to 201.3 tons. At the turn of the century the figure was 485.4 tons.

During the first world war gold production decreased. In 1938, however, the world outside the Soviet Union mined 1,163 tons, and 1,268 tons in 1940.

The second world war brought about another decrease in gold production, so in 1945 as little as 812 tons of the metal was mined. In 1950, however, the eight leading gold-producing countries, leaving out the socialist countries, scored 1,011 tons, and 1,067 tons in 1960.

The bulk of this gold is mined in Transvaal. Mines some three kilometres deep reach for gold-bearing veins there. The temperature in the workings never drops below 35-40°C. In back-breaking toil the miners, mostly Kaffirs, get gold, the yellow metal bearing fat profits for the mine owners.

Much gold has been found in many places throughout the Soviet Union. Skilful goldsmiths have long been the pride of many Russian towns.

A short distance from Sverdlovsk in the Urals, right beyond a students' community, lies Lake Shartash. On its shores you can still see the log cabins of a village which bears the same name. In 1745 Yerofei Markov of this village came upon a goldfield, the first in the Urals. Named "Berezovskoye", it became the beginning of a gold-mining industry in Russia. Then more deposits were found in the Yenisei valley and the Lake Baikal area, and gold production made a steep rise after 1820. Further impetus was given by the discovery of the now famous gold placers in the Lena valley.

Finally in the 1850's gold placers were discovered along the river Amour, and in 1871 in the Primorye Territory. Russia had become a major gold-producing country. By 1923 it had mined a total of 2,879 tons of gold, with an all-time record of 63.7 tons scored in 1910.

Work was unbearable at the gold mines of tsarist Russia. The official working day for hired gold-diggers was eleven and a half hours, but in summer they often worked sixteen hours. Strikes were a common thing. The biggest of them took place at the Lena goldfields on April 4, 1912. It has come down into the history of the revolutionary movement of Russia.

Right after the October 1917 Revolution the Soviet Government took every effort to change the situation in the gold-mining industry, and al-

ready in 1933 gold output in the Soviet Union exceeded its production in tsarist Russia. Once a primitive trade, gold-mining has now become a modern, highly mechanized industry.

GOLD NUGGETS AND GOLD ORE

Most often gold occurs as small grains, or gold dust. Sometimes it is found as nuggets which may be fairly large in size and weight. The biggest nugget in the Soviet Union has been found in the southern Urals. It weighs 35 kilograms and is kept in a museum. The world's biggest nugget has been found in Australia. You can hardly lift it single-handed; it tips the scales at 111.6 kilograms.

Native gold is never pure; it contains five to thirty parts silver, up to twenty parts copper in a hundred, and some other impurities. Most often it occurs in thin veins embedded in quarts ("vein" or "reef" gold). With time the bedrock erodes, the gold breaks loose from the quartz, and water carries it away. As it is very heavy, gold deposits in rivers and rivulets as placers (hence "placer" or "alluvial" gold), from which it is recovered by "panning".

I bet you've read either Jack London or Mamin-Sibiryak and know what "panning" is. Just in case you haven't, a pan is a circular dish with sloping sides. It must be light but stiff to stand rough handling. The gold-digger loads his pan with gold-bearing gravel from a placer, dips it in water, thoroughly wets and stirs the gravel by hand to break up lumps of clay, and picks out the larger stones. Then the pan, still under water, is given a shaking motion to bring the lighter material to the surface and allow the heavier particles to settle. At intervals the man tilts his pan, and the surface material is washed off. He goes through the steps again and again, until nothing but gold and a little heavy sand is left. In skilled hands little or no gold is lost in panning.

Panning is slow, back-breaking work. It requires only a pick, shovel and pan; this is why it has been a favourite poor man's method.

A more advanced way of gold recovery is sluicing. A sluice is an inclined channel or trough in which gold-bearing gravel from a placer is carried by a stream of water. The bottom of the sluice may be covered either with a metal screen having holes punched in it, or with hemp mats making up so-called riffles. Stones and light sands pass through and run to waste at the lower end; gold and other heavy minerals settle to the bottom and either fall through the screen or are caught in the riffles.

If gold is accompanied by native copper, they will stay together. Nor can water wash off "black sand", or magnetite; instead it is removed by a magnet.

Large-scale gold mining, however, relies mostly on dredging. A placer mining dredge combines an excavator, screening and washing plant, both mounted in a floating hull. Dredges can work on depths up to a good twenty-five metres. The steel jaws of a dredge lift bucketfuls of gold-bearing gravel; the gravel is crushed, washed and discharged already freed from its gold burden.

As a dredge floats down a river, it works the river's bottom from bank to bank. Its crew is small, but they can handle a large yardage of gold-bearing gravel. It pays to use dredging where gold assays as little as a few tenths of one gram per ton of muck.

After crushing and sometimes concentration, gold ores carrying no other values are "amalgamated". For this, mercury is added to the "pulp", or crushed ore, and the two metals form an alloy known as amalgam. After the amalgam has been separated from the gangue, the surplus mercury is removed by squeezing the amalgam through chamois or canvas bags. The squeezed amalgam containing twenty to fifty parts gold in a hundred is finally retorted to drive off the mercury which is then condensed and returned for another cycle of amalgamation. The remaining retort metal is melted to separate the silver and to get rid of the impurities.

However, amalgamation cannot recover other values contained in the ore. Nor can this process catch all the gold originally present. This is why use is often made of cyanidation, also known as the cyanide process. By this process gold and silver are extracted from their ores by means of the solvent action of an alkaline or alkali-earth cyanide solution. From the solution the gold is then brought down with zinc dust. Cyanidation and other hydrometallurgical processes, as originally applied to gold, have proved so efficient that with suitable modifications they have now come to be used for the recovery of uranium, zinc, and copper.

Gold recovered by any method carries many impurities and it has to be refined. This can be done in several ways, the last stage usually being electrolysis. Finished gold has a fineness of 999.9 parts in a thousand, or simply 999.9.

FINENESS

"Fineness" is a jeweller's term. It defines the purity of the noble metals.

The practice to test, or assay, the noble metals for purity was started in ancient Egypt some forty centuries ago. Naturally many systems have come and gone since then.

In the Soviet Union and some other countries fineness is expressed in parts per thousand. Thus one kilogram of an alloy containing 250 grams of impurities will have a fineness of 750. Soviet jewellers use gold 375, 500, 583, 750 and 958 fine; silver 750, 800, 875, 916 and 960 fine; platinum 950 fine; and palladium 500 and 850 fine.

This "metric" system was introduced in the Soviet Union in 1926. Before it, use was made of the so-called Russian system based on the Russian pound containing 96 zolotniks. Thus gold 92 fine contained 4 zolotniks of impurities per pound; silver 88 fine had 8 zolotniks of impurities.

In Britain, Switzerland and elsewhere fineness is measured in carats, or twenty-fourths. A noble metal of the highest purity is said to be 24 carats fine. If the mass contains 22 parts of gold and two of alloy it is 22 carats fine, or 22-carat gold.

The reader might ask why so many impurities are allowed to remain in the noble metals. In fact, they are added deliberately so as to give the final alloy the desired strength or colour. These additions are measured amounts of copper, silver, cadmium, nickel or palladium. Each works in its own way and each gives a particular tinge, red, pink, green, blue or even white to the alloy. This is why jewelry differs in colour so widely.

Each gold ring, silver spoon or any other article of a noble metal has a hall mark stamped on it to indicate its ingenuity. If you look at the hall mark of an article made in the Soviet Union you'll see a worker's head, a three-digit number, and several letters. The worker's head is the mark of origin, symbolizing the Soviet Union. The three digits are the assay mark giving the fineness we've just spoken about, and the letters following it indicate the government assay-office where the metal was assayed.

This is not the only hall mark used in the Soviet Union. The hall mark on an article made after June 1, 1958 includes a five-pointed star, hammer and sickle as the mark of origin. The mark of origin on articles made in Russia before the October 1917 Revolution is a woman's head with a frontlet. Naturally, altogether different hall marks are used on things made in other countries.

In an assay office they do not necessarily carry out a complete chemical analysis on, say, a gold article. Instead, they use the touch stone, a mineral of sufficient hardness and having a dull black surface. First a streak three or four millimetres wide is drawn on the stone with the article being assayed. Next to it another streak as wide is made with a "needle" of an alloy of known fineness. If the streaks are the same in colour, the tested article has the same fineness as the standard. If they differ, an additional test is applied. The two streaks are wetted with a special solution. A chemical reaction takes place producing a finely divided powder of gold. Its colour depends on the content of impurities. If the article carries more impurities

than the standard, its streak will be lighter in colour; if less, the streak will be darker compared with that of the standard.

By this method an experienced assay officer can determine the fineness of gold accurate to three units, and of silver to five units. This is quite enough for most practical purposes.

THE YELLOW METAL

Gold is one of the heaviest metals. A cube of gold with a side one centimetre high weighs 19.25 grams, or more than twice as much as iron. When free from impurities, it is bright-yellow, very tough and malleable.

Using this property, a skilful master can beat gold into very thin leaves. First a piece of gold is rolled to a thickness of writing paper. Then the strips of rolled gold are piled between sheets of the membrane stripped off oxen's liver, and are beaten carefully, then trimmed and beaten again between fresh sheets of the liver membrane. After the final beating very thin leaves down to 0.00001 mm thick can be obtained, transparent to bluish-green light.

By the same technique, silver-gold leaves can be prepared by piling silver and gold strips between sheets of the liver membrane. The leaves are then yellow on one side and mirror-white on the other. Gold and silver-gold leaves are used in gilding furniture, books and many other things. In old Russia much gold leaf went to gild ikons and church accessories.

Gold is not particularly strong. When annealed, it has an ultimate tensile strength of 12 kilograms per square millimetre. It is so soft that a finger nail will leave a trace on a strip of pure gold.

Gold melts at 1063°C. On further heating the molten gold gives up yellow-green fumes, gaseous gold. At 2970°C it boils.

Gold has an enviable chemical stability (it wouldn't be bad for iron to have such a property). It does not dissolve in either alkalis or acids. It succumbs only to a mixture of acids like aqua regia, and to cyanide solutions in the presence of oxygen. It is not too eager to enter into reactions, and its compounds, if you're lucky enough to obtain them, will easily decompose, some on heating, others simply under the action of light.

This is why all gold we do use is alloyed with either silver, copper, platinum or mercury.

Silver-gold alloys display a whole gamut of colours and tints. Small amounts of silver produce a pale yellow alloy; amounts up to thirty-five

parts in a hundred give an alloy having a distinct greenish tint. All gold-silver alloys (they are made into jewelry) are soft and malleable. Annealing makes them hard and brittle, and quenching gives them softness and ductility—just the opposite as with steel.

Alloys of gold and copper are used for coinage, jewelry and dentures. Gold-platinum alloys with an addition of silver are used in the manufacture of electrical contacts.

These are about all the uses of gold alloys.

THE DOME OF ST. ISAAC'S CATHEDRAL

The dome of St. Isaac's Cathedral, the most beautiful in St. Petersburg (now Leningrad), was to glisten high above all the buildings in the city. Twenty-two metres tall and supported by heavy columns fashioned from huge blocks of granite, the dome was therefore covered with sheets of copper. And to make it glitter like, or even better than, the Sun, the copper was gilded.

The heavy sheets were ground, polished, and degreased by rinsing with acid. Then they were amalgamated—rubbed with semiliquid yellow amalgam, and placed on braziers filled with glowing charcoal. A light bluish-green smoke rose above the sheets, the fumes of mercury, and the copper began to glitter like the Sun.

This was repeated two or three times, until the coat of gold was three to five microns thick.

At first glance the men handling the copper sheets under the shed over the braziers were doing a much easier job than the stone-masons and navvies. But that was so only on the face of it. The men who had gilded the copper sheets later all died a horrible and painful death. Physicians, if they had examined them, would have stated "death from mercury poisoning". The cost of the thin coat of gold on the dome of St. Isaac's Cathedral was paid with many human lives. And that it can stand up to the attack of the elements for a good century and a half is hardly a consolation.

The life-killing method was done away with after the invention of electroplating, that is, a way of covering things with a metal in an electrolytic cell by means of an electric current. The deposit is no less strong than one obtained by a "fire" method.

Electroplating was used to gild the copper domes of the Annunciation Cathedral in the Moscow Kremlin, the spire of the Peter and Paul Fortress in St. Petersburg, and the framework of the ruby stars on top of the Kremlin towers.

Gold plating can produce different colours. An addition of copper cyanide to the electrolyte will give a red deposit. The combination of copper cyanide and silver cyanide produces a pint tink. If silver cyanide is added alone, the deposit takes up a green colour.

A still better method is sputtering which came about in the second quarter of this century. By this method an extremely thin coat of gold can be deposited, sometimes as thin as a few thousandths of a micron. Sputtering is employed in the manufacture of photocells, so-called "coated" optical lenses, grammaphone records, and the like.

Sputtering boils down to the following. The surface to be coated is laid on a base plate which is the anode of a gas discharge tube evacuated to a low pressure. The metal to be deposited is made the cathode. The high voltage applied to the cathode makes it disintegrate to positive ions. The ions strike at the material on the anode and form a thin deposit. This method can be used for depositing thin metal films not only on metals, but also on paper and wood.

Incidentally, it was usual to gild wooden things a long, long way back. In Egypt, some five thousand years ago, this was done with gold leaf. Gold leaf was applied to sedan chairs, sarcophagi and other things for pharaohs and their courtiers. In Russia this method was in use from the 11th to the mid-19th century for gilding the domes of churches, the roofs and spires of palaces. Gold leaf was bonded to a copper or iron base with suitable adhesives, called gold size. But gilding like this seldom lasted for more than fifty years when subjected to daily use or exposed to the atmosphere.

Still another gilding method is with powdered gold bonded to the base with gold size.

But none of these methods can compete with gold plating.

A RIVAL OF PAINTERS

Many things had happened before photography became as we know it today.

Way back, in the middle ages, it was noticed that lunar caustic, a compound of silver and nitrogen, would darken with time. But several centuries were to pass before photography came into being in 1839. Its creator was Louis Daguerre, a French painter. A photograph taken by his process was called a daguerreotype. Daguerreotypes were taken on thoroughly polished silver plates sensitized by iodine and developed by exposure to mercury vapour. The person who wanted his daguerreotype taken had to sit immobile for at least half an hour. Today the time of exposure has been reduced to a few thousandths of a second—an amazing improvement!

Still images have given way to motion pictures. But today, as before, the basic material is silver in a multitude of compounds. Today, as before, the basis of any photographic process is the ability of silver compounds, such as silver bromide and silver chloride, to change in chemical composition under the action of light.

Like gold, silver is a noble metal, and like gold it occurs in native form although more seldom. Man began to use silver probably at the same time with or a bit later than gold. In Asia Minor they knew how to smelt silver from its ores already in 3000 B.C.

Silver is white in colour and is much lighter in weight than gold; its specific gravity is 10.49. It melts at 961°C and boils at 1955°C. Like gold, silver is highly ductile and malleable and can be given an exceedingly high polish.

When polished, silver reflects light better than any other metal, sending back over nine-tenths of the incident light. This is why silver goes to make mirrors, not for our homes of course, but for telescopes and other optical devices.

Silver is superior in electrical conductivity to copper, the chief metal of electrical engineering. For this reason silver is used in the manufacture of wire for precise physical instruments, in making joints in radio equipment, and in contacts and terminals for relays.

Although more chemically active than gold, silver is not oxidized in air. A silver spoon can be exposed to air for as long as you might care, without showing a trace of oxidizing, provided the air is free from hydrogen sulphide or sulphur oxides.

These gases are silver's most formidable enemies. Sulphur dioxide is usually present in the air of big cities where it is given up by burning coal. Hydrogen sulphide is produced by rottening organic substances, including bad eggs. A silver spoon which has remained bright for years would tarnish at once if you eat not too fresh an egg with it. The culprit is hydrogen sulphide.

An interesting property of silver is what scientists call its germicidal effect. It was noticed long ago that water poured in silver vessels would not become foul. This is because the silver ions that pass into solution kill many bacteria. Even when poured into glass bottles, such water will stand long storage. For the same reason—the germicidal effect—it is good to use silver spoons. For the same reason silver is made into pipelines, nozzles and other parts in dairy, cider and brewing industries and as vessels in food processing.

To the uses of silver we've already mentioned should be added the manufacture of tableware and jewelry.

The world produces five times as much silver as gold. In 1953 its production outside the socialist countries was about 5,520 tons.

When he hears about native platinum, the geologist cannot say at once what sort of platinum it is. For chemically pure platinum does not occur in nature. What is known as native platinum is in fact a group of alloys of platinum, iron, copper, nickel, palladium, iridium and rhodium. In them platinum runs an average of eighty parts in a hundred.

Platinum is seldom found in nuggets and then only of small size. The biggest weigh eight to nine kilograms. Ordinarily native platinum is found in small grains, or flakes.

Like native iron and silver, native platinum was known long ago. It was named "platinum" by the Spaniards who brought this metal from South America in the 16th century. It may be added that the Aztecs knew how to work platinum. Their last emperor Montezuma II sent exquisite mirrors of platinum as a gift to the Spanish king. We still do not know how the ancient American metallurgists worked this refractory metal.

The first notable development of platinum came with its discovery in the Urals, Russia, in 1819. This was the source of about nine-tenths of the annual production in the world until 1914. From 190 kilograms of platinum in 1825, its production rose to over two tons in 1870, and to over seven tons in 1913. The other suppliers were Columbia, Alaska and Canada.

Today more than half the annual production in the world comes as a by-product in the electrolytic recovery of nickel and copper in Canada. The Soviet Union continues to recover much platinum, while Columbia and Alaska add sizeable amounts. South Africa, too, has become a major supplier. In 1960 the world outside the socialist countries produced about 16.6 tons of platinum.

Platinum has about the same colour as tin, but it is heavier than gold; its specific gravity is 21.4. It is highly refractory, melting at 1773°C and boiling at 4400°C.

Pure platinum is soft, readily malleable and ductile. It can be drawn into wire 0.001 mm in diameter. Its most valuable property, however, is chemical inertness; it resists attack by the single acids, although it dissolves in aqua regia. It will not oxidize in air, even when heated. This is why platinum is used as crucibles, dishes, tubes and gauzes. It is also made into boilers and retorts, for it also retains its strength at high temperatures.

Perhaps the most interesting use of platinum is as a catalyst, that is, a substance which causes or speeds up a chemical change in other substances without being changed itself. It often happens in the chemical industry that reactions go on at a snail's pace, if at all. Nothing helps to hasten them, neither heating nor high pressure. This is where a catalyst comes in.

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In some cases the catalyst is platinum. Its presence speeds up chemical reactions tens of times. Incidentally, platinum is used as a catalyst in the commercial production of sulphuric acid.

Yet the major consumers of platinum are jewellers who take about two-fifths of all the platinum produced. Then come chemistry with one-fourth, the electrical industry with one-seventh, and dentists with one-tenth.

PLATINUM'S COMPANIONS

Early in the 19th century platinum was found to be combined with five other noble metals which today, together with platinum, are known as the platinum group. To the geologist or the chemist these five metals, palladium, iridium, rhodium, osmium and ruthenium, are as closely associated with platinum as Phobos and Deimos are with Mars to the astronomer.

To separate the platinum metals, crude platinum is completely dissolved in aqua regia. Then suitable reagents, such as ammonium chloride, sugar or others, are added to precipitate the desired metal.

Of the five companions we know iridium best. It was discovered by the British chemist Tennant in 1804, when he dissolved grains of native platinum in aqua regia. In the residue he found two new metals. He called one of them "iridium" for the fact that it showed colours like those of a rainbow.

For the first time pure iridium was obtained by Kozitsky of Russia. It turned out to be a very heavy metal with a specific of gravity 22.4, and very refractory, melting at 2454°C and boiling at over 4800°C. Iridium is still more inert than platinum. Even aqua regia does not attack it at room temperature. Only when finely divided can it be brought into solution by this reagent.

Iridium is very hard and resists abrasion. This is why it is used for tipping surgical instruments, fountain-pen nibs and magneto contacts.

An interesting occurrence is as an alloy of about equal proportions of iridium and osmium, the so-called osmiridium or iridosmine. It is very hard and is used in bearings for watch movements and precise instruments.

The standard metre of Paris, the basis of all the metric or decimal system of weights and measures, is constructed in an alloy of ninety parts platinum and ten parts iridium. This alloy has been chosen for strength, hardness, high melting point, and resistance to wear, ageing and corrosion.

All "national" metres copied from the Paris standard are made in this alloy. In the Soviet Union it is kept in the USSR Chamber of Measures and Weights.

Standing before iridium in the Periodic System is osmium, the heaviest of all known elements, with a specific gravity of 22.5. It takes just a little bit more than four cubic centimetres of osmium to make a weight of 100 grams.

Osmium is a little known element. It is similar to iridium in hardness, brittleness and resistance to attack by acids. On heating in air, however, it gradually oxidizes even at slightly above 100°C. It melts at about 2700°C. Of all metals, it naturally alloys only with iridium. Of late synthetic alloys with ruthenium and other platinum-metals have been developed. Osmium compounds are used in medicine and biology, especially as stains in sections for microscopic studies.

Palladium is the third of the platinum group. Like iridium and osmium, it is rare and scattered. For the first time it was isolated from platinum by Wollaston, a British chemist and physicist, who named the new metal after a just discovered asteroid.

Palladium melts at as low as 1554°C and is half as heavy as osmium or iridium with a specific gravity of 12.1. It is soft and ductile, and can be easily worked, hot or cold.

It is the most chemically reactive of the six platinum metals. It readily oxidizes in air when heated and is attacked not only by aqua regia, but also by nitric acid.

Palladium has the interesting ability of absorbing gases. At room temperature it will absorb up to 800 times its own volume of hydrogen.

Pure palladium is an excellent metal for electrical contacts, and much palladium is used in the telephone service. A silver alloy of palladium goes to make resistance windings. Alloyed with platinum, it is an excellent material for thermocouples. In dental alloys containing gold and platinum, palladium improves the strength and toughness.

Suitably hardened, palladium can be made into spinnerets for the manufacture of man-made fibre. When finely divided, it is a very good catalyst. Beaten into leaves, it is used for decorations on ceramics and book bindings. Base metals clad with palladium are used in equipment for making fine chemicals.

The same Wollaston discovered still another metal of the platinum group in 1803. Its compounds usually show attractive pink and red colours.

For this reason the discoverer named the new metal "rhodium", from a Greek word meaning "rose".

The properties of rhodium were studied much later. It has been proved fairly average among the other platinum metals. It melts at 1966°C. Its specific gravity is 12.4. It oxidizes only when heated to anywhere between 600° and 1000°C. Single acids do not attack it, and aqua regia does so but little.

Rhodium is mainly used as an alloying addition to platinum and palladium. It improves the mechanical strength and heat resistance of platinum for use in crucibles and the resistance windings of high-temperature laboratory furnaces. Alloys containing ten parts platinum and thirteen parts rhodium in a hundred make very good thermocouples for high-temperature work, magneto contacts, and spinnerets for rayon production. It is also used as an electrodeposit in reflectors for searchlights.

The last among the platinum metals to be discovered, by Claus in 1844, was ruthenium, named after Russia where Claus was working at the time. Ruthenium melts at 2450°C and boils at 4150°C. Its specific gravity is 12.2, or about the same as that of rhodium or palladium. Like the other platinum metals, it absorbs many times its own volume of gases. On heating it oxidizes in air, but resists attack both by single acids and by aqua regia. It is very hard and brittle, because of which it is almost unworkable. Its chief use is as an alloying element, practically always with other metals of the platinum group. It is also used as a catalyst and as a pigment for porcelain.

THE LIQUID METAL

If it were not its amazing ability to remain liquid down to 38°C below zero, quicksilver, or mercury, would have been as much used as the noble metals. It would have been made into coins, gem settings, cups and goblets. For in chemical stability mercury is very close to gold and silver. It is gold's neighbour in the Periodic System. Like gold and silver, though not so often, mercury is found native. Since, however, only the Snow Queen from Andersen's fairy tales could have some use for decorations in mercury, altogether different applications have been found for this remarkable metal in modern technology. Instead of jewellers, scientists and engineers are dealing with it, the heaviest of all known liquids (its specific gravity is 13.6). To them mercury is probably more valuable than gold or silver.

Mercury does a lot of jobs—in mercury-vapour lamps, mercury-arc rectifiers, and many physical instruments, the commonest of which is the mercury-in-glass thermometer. Metallic mercury was used at the dawn of the present era in the recovery of gold by amalgamation. Mercuric fulminate is a detonating agent. Mercuric oxide is added to so-called anti-fouling paints applied to the bottoms of ships as protection against barnacles or other marine growth. Farmers use mercuric compounds as seed disinfectants. Many compounds of mercury are used in medicine. Gold can hardly boast of as many uses!

And now I'll take you on an imaginary visit to Haydarkhan where metallic mercury is produced from its ore cinnabar.

The works is situated in a mountain valley, some 1,500 metres above sea level. Centuries ago our forefathers mined cinnabar here, and even today you can run into their old workings. They unmistakably lead to veins of cinnabar. How the ancients could possibly locate its deposits so accurately remains a puzzle yet. Or could they? For we find skeletons in great numbers in the old mines. Or these may be the remains of the slaves who used to mine for their owners this valuable metal which was made into the most ancient synthetic drugs known.

Clicking and clacking at the joints, an electric locomotive pulls a train of cars from the black hole of a tunnel leading inside the mountain. Among the lumps of quartz filling the cars you can see stones as if stained with blood. This is cinnabar, the ore of mercury. From the cars the ore is dumped into the hopper of a crusher, that gate to the factory.

In fact, the factory does not look like one. It has no brick buildings for the machinery. The whole plant is set up in the open. The wholesome breeze from the mountains reaches every worker on the premises. Probably this is why vocational diseases, almost inevitable in work with mercury, do not occur here.

The crushed ore is charged into rotary kilns, huge inclined cylinders about fifteen metres long and over two metres in diameter. The ore enters a kiln at the raised, or "cold", end. The lower, or "hot", end fits into a fire hood where nozzles squirt a fuel into the kiln. When the operator opens the door in the fire hood, you can see a searing flame raging inside it and piercing the white-hot slope of the charge which slides down as the kiln rotates. Heated to about 800°C, the ore decomposes into sulphur dioxide and mercury. The vapours of mercury are carried off by the sulphur dioxide, and the calcine is discharged into a waste hopper.

The whirlwind of hot gases also carries along a good deal of fine dust. To get rid of it, the gases are passed through cyclones. In them, the stream of gases is wound into a tight spiral, and centrifugal force separates the solid particles. Thus purified, the gases are passed down earthenware pipes arranged in long rows next to the kilns. These are condensers. In the con-

densers, the vapours of mercury are turned to metallic mercury. The liquid metal is collected in a vat some ten metres long, under a blanket of water. Oxides of antimony and arsenic, some fine ore dust and other materials also find their way into the collector for all the efforts to purify the gases. This is why metallic mercury is finally washed with alkalis and nitric acid. They remove the last traces of the impurities.

Mercury of the highest purity is poured into porcelain jars holding five kilograms each. Commercial mercury is shipped from the factory in steel flasks. Each holds thirty-five kilograms of this valuable metal. You will hardly be able to lift it unassisted.

All the operations in the production of mercury—roasting, dust precipitation, condensation and washing—are carried out in a vacuum. This is why not the slightest trace of mercury-carrying gases can escape into the atmosphere. In fact, the outside air tends to break in through whatever cracks may happen in the apparatus.

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THEIR TIME
WILL COME
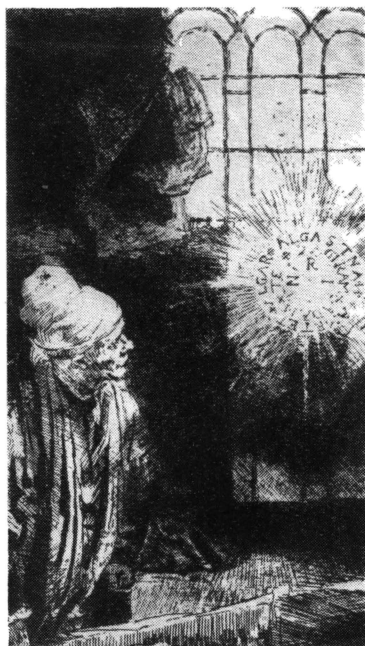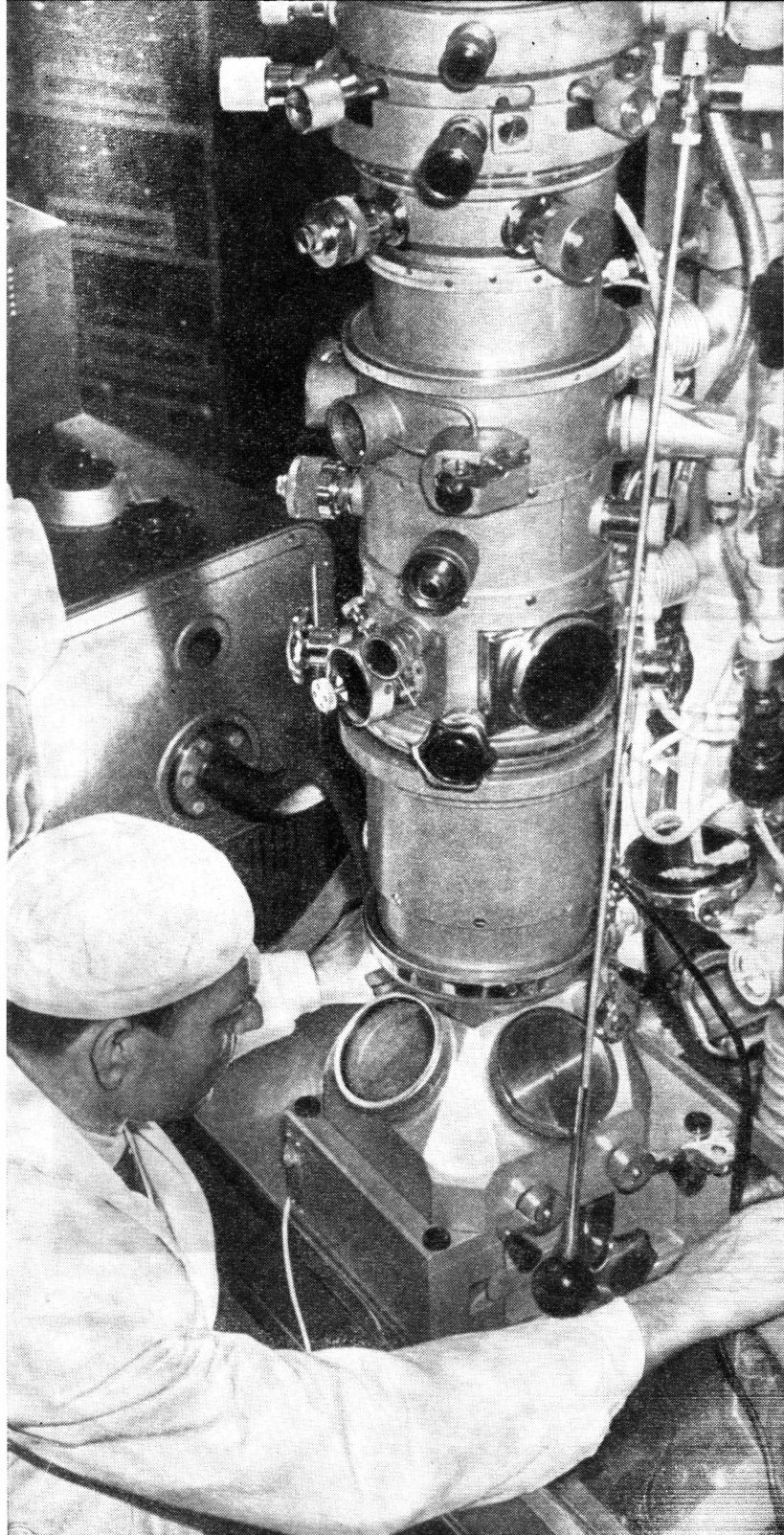
█t is less than a century back to the time when Mendeleyev proposed his Periodic System. Much less time has passed since the vacant places in the System were filled. Yet most of the elements have proved useful to man already.

Not that this happened to every new element at once. Many of them had remained good-for-nothing curiosities for a long time before their remarkable properties were discovered. Then the demand for them would grow in no time, and metallurgists would be busy looking for ways and means of meeting this demand.

This has happened to aluminium, for example. It was looked upon as a noble metal only several decades ago. Then aviation took interest in it, and its production today is more than three million tons a year.

This has happened to tungsten, the component of "hard metals", electric-lamp filaments and high-quality steels.

This has happened to cesium, the metal of photo-electric cells.

More recently, this has happened, or rather, is happening to titanium and germanium.

Now which of the yet unused metals will attract physicists, chemists and technologists tomorrow?

It is anyone's guess. About them we can only say that their time will come.

So let's make the acquaintance of these metals scattered around in the Periodic System.

A TANGLE OF PUZZLES

There is, in the Periodic Table, a square occupied not by one, but by fifteen elements. They are known as the rare earths. They are not so rare as you might think, though. Some of them are more abundant than cobalt, zinc or lead which are widely used in engineering. There is more cerium on the Earth than cadmium, antimony, molybdenum or gold. Together the rare earths account for 0.017 per cent of the planet's crust by weight, which is not little.

The rare earths have quite a number of minerals of their own, occurring in the Americas, Scandinavia, Finland, the Kola Peninsula, the Urals and elsewhere.

Why is it then that these elements have been so poorly studied so far?

This is because they have all the same outer electron shells and, therefore, the same chemical properties. It took several generations of chemists over a century and a half just to learn which elements make up this tangle of puzzles. In fact, chemists have not yet held some of these elements on their palms—they have not been isolated in pure state.

In 1794 Gadolin of Finland isolated a chemical compound which he called the yttrium earth, or yttria (you remember that the name "earth" was then applied to any metallic oxide not reducible by existing methods), since he believed that he had obtained an oxide of yttrium, a new metal. Although yttrium occupies a place of its own, just above the "hostel" of the rare earths in the Periodic Table, it is so similar to and always occurs with them that it was regarded as one of the family for a long time.

Yttrium metal was obtained by Friedrich Woehler of Germany in 1828. It was not a pure metal. It contained a good share of the "relatives" from the "floor" below. In fact, pure yttrium has not been prepared yet, and even its specific gravity has been determined only approximately, to say nothing of its other properties.

But yttrium started the chain of discoveries that led to the rare earths. In 1843 erbium and terbium earths (also known as erbia and terbia) were isolated from yttria. In another fifteen years, the ytterbium earth, or ytterbia, was separated from erbia, and ytterbia was broken down to yield scandia, while erbia yielded thulia. Later, the metals erbium, terbium, ytterbium and thulium were prepared from them. Scandium proved a separate element occupying a place of its own, two "floors" above the rare earths and just above yttrium.

Scandium, discovered by L. Nielson of Sweden in 1879 and named after his native peninsula, is very similar to the rare earths in chemical properties. It is so scattered in the Earth's crust that only very few chemists have been lucky enough to prepare it in pure state. It has a specific gravity of about 3.1, a melting point of about 1300°C, and a boiling point of 2400°C. Chemically it is less active than yttrium and the rare earths. It may so happen that this metal will find many uses, unless its scarcity prevents studies of its properties and potentialities.

So, yttria proved to contain six elements, two of which did not even belong to the rare earths. But the "yttrium clue" was something to go by. Also there was another "clue" to work on from the other end—the cerium earth, or ceria.

It was obtained by Berzelius of Sweden in 1803. It, too, proved to carry a whole family of earths. Finally, they were reduced to the metals cerium, lanthanum, praseodymium, neodymium, and samarium. That was how the tangle of puzzles was disentangled, although the last, fifteenth, element of the series has not been found in nature. Named promethium, it is found only in the products of uranium fission. It was first identified in 1947.

So the name "rare earths" has a purely historical significance, as a reminder of their past. Chemists have proposed another name for the elements—"lanthanides" or "lanthanons", after lanthanum, the first in the rare-earth series.

The lanthanides are silver-grey metals which tarnish quickly in air. They decompose water slowly at room temperature and rapidly when heated. They readily react with most non-metals.

While the lanthanides are very similar in chemical properties due to their similarity in atomic structure, they differ in physical properties. Praseodymium, for example, is yellow like copper, while dysprosium looks like silver, and cerium resembles lead. Melting points vary from 310°C for terbium to about 1800°C for ytterbium. While samarium can vie with the best steels in hardness, lanthanum and cerium can be cut with a knife. But it must be admitted that scientists have not yet pulled all the threads from this ball of metals. It may well hide something that would revolutionize whole industries or divisions of engineering.

Although our knowledge of the rare earths is not complete, they have already found many uses. The cerium-iron alloy is used for flints in automatic lighters. If you strike a piece of this alloy slightly or rub it against a rough surface, a shaft of sparks will fly out. The sparks are burning grains of cerium; it ignites in air at about 165°C and gives out a bright, dazzling flame.

Cerium has been studied best of all the lanthanides. The German chemist Klaproth who discovered it in 1803 named cerium after Cerera, a newly discovered planet. As you see, this tradition of calling new elements after planets still holds.

Cerium has a specific gravity of 6.8, melts at about 793°C and boils at nearly 2690°C.

And what remarkable is there about lanthanum, which has given the name to the whole lot?

For the first time the lanthanum earth was isolated by Mosander of Sweden in 1839. The name "lanthanum" comes from a Greek word meaning "hide". As has now been learned, the element has nothing particular about it. Its specific gravity is 6.1 and its melting point lies somewhere between 820° and 850°C. Yet, the element may well only look unattractive because we haven't been able to learn it better and it is still living up to its name.

Lanthanum has a twin in praseodymium, from a Greek word meaning "a pale-green twin". It was called so by K. Welsbach of Austria who first isolated its salt. He was also the first to isolate the salt of yet another twin of lanthanum's, the metal neodymium, from a Greek word for "a new twin". The two are used together under the name of didymium.

Samarium was discovered by L. de Boisbaudran of France in 1879 in the mineral samarskite, so called after the Russian geologist Samarsky. It is a greyish-white metal of specific gravity 7.7. The most interesting feature about it is that some of its compounds are fluorescent, being topaz-yellow in colour. Because of this they are used in phosphors.

The same use is made of the salts of europium, the rarest of all the rare earths (leaving out promethium which does not occur in nature at all). It was discovered by the French chemist E. Demarsé in 1901. Its name is self-explanatory.

The name of gadolinium was given in honour of the Finnish chemist Gadolin by J. Marignac of Switzerland who discovered it in 1880. Some of its salts have helped man to approach absolute zero in temperature. On demagnetizing, they cool. So they are brought as far down as possible in temperature while magnetized and then are demagnetized. Now their temperature drops of its own accord.

About terbium, that twin of gadolinium, we know practically nothing except that in a mixture of gadolina its oxide terbia produces a yellow tinge.

The same is true of the mixture of terbia and dysprosia, the oxide of dysprosium (from a Greek word meaning "hard to get at"). Although dysprosium has been studied very little, it promises to turn out very interesting. Its compounds are the most paramagnetic of all known materials. Dysprosia, for example, is fifteen times as paramagnetic as iron. The palm in paramagnetism, though, is shared by holmium which was discovered by

P. Cleve of Sweden in 1879 and named after Stockholm. This seems to be all that we know about this metal.

The existence of an earth which was called by Mosander as erbia was at first discounted but later was confirmed. This earth was then renamed terbia because in the meantime the name erbia had been given to a rose-coloured earth. When heated the latter gives out a bright green colour. The metal erbium forms a rose-coloured oxide and salts of the same colour. Very little might be added to this knowledge of erbium which occurs in fairly large amounts in yttria.

Thinking up a name for another new element, Cleve showed rare originality. He named it thulium after Thule, the mythical country supposed by the ancient Greeks and Romans to be the most northerly region in the world. Thulium is eager to be put to some use. It may prove very efficient in X-ray units and phosphors. The only roadblock to its utilization is the difficulty of producing it in pure form.

Speaking of names, the biggest share of luck has fallen to the small village of Ytterby in the island of Ruslagen, Sweden. It was in a quarry not far from Ytterby that the famous mineral gadolinite was found. The rare-earth metals erbium, terbium, yttrium and ytterbium identified in gadolinite were all named after the village. We've already mentioned the first three. The only thing we can say about the fourth is that it is very little studied.

The closing element of the lanthanide series is lutecium. For the first time it was isolated by the French chemist T. Urbin in 1907 who named it so after Lutetia (the Roman name of Paris). But metallic lutecium has not been prepared yet.

No, the riddles of these fifteen elements have not yet been fully unpuzzled. Many problems, intriguing and vital, are still awaiting a solution.

Metallurgists have noticed that additions of the rare-earth metals, usually as their alloy misch-metal, give important properties to magnesium and aluminium alloys. But which of the lanthanides is most important is not known. It may well be that tomorrow one or several of them will become as essential to steel-making as tungsten, chromium or nickel.

Cerium, also added as misch-metal, improves the properties of nickel-chromium alloys. It may well be that other rare-earth elements can serve as alloying agents of alloying additions!

An addition of eight parts cerium in a hundred to aluminium-copper alloys make them resistant to acids and water. How will they behave if, instead of cerium, they are alloyed with as much erbium or lutecium of which not a single grain has been obtained to date?

The tangle of puzzles still has something for investigators to work on. For many investigators, because this is not a one-man project.

The space between these two metals in the Periodic Table is occupied by the metals zirconium, hafnium, tantalum and niobium (known as columbium in Britain). They all differ in properties, the history and, apparently, the future. What unites them is that they are just beginning to be used and hold out great promise to the technologist.

The lightest of the four is zirconium, the immediate neighbour of the amazing titanium. It was discovered by Klaproth of Germany in 1789 while he was studying semi-precious stones from Ceylon. It was named after the mineral zircon. It is fairly abundant, comprising 0.028 per cent of the Earth's crust. Its known deposits are greater than the combined amounts of copper, zinc, tin, lead, nickel, and mercury. Zirconium occurs in a great number of minerals. But one hundred and fifteen years had passed before chemists could isolate metallic zirconium. It was prepared in 1914. It is of specific gravity 6.25, melts at 1830° and boils at 2900°C.

Zirconium looks like steel, but is superior to it in many properties. In pure form, it is stronger than a good quality of steel. At the same time it is very ductile and can be drawn into wire. In resistance to corrosion it is superior to titanium and to stainless Cr-Ni steel. Neither diluted sulphuric acid nor nitric acid of any strength can attack it. Nor can aqueous solutions of alkalis do any harm to it. Only strong sulphuric acid dissolves zirconium.

Those are all attractive properties for a structural metal, aren't they? To them must be added a still more valuable and rare property. Zirconium captures very few slow electrons or, as physicists put it, it has a low effective capture cross-section. This is a very vital property for a material widely employed in nuclear reactors.

Now it is clear why zirconium has become so prominent as a material for advanced technological applications. And its production has been rising steadily although not so rapidly as that of titanium.

In 1947 the United States started a pilot-production plant with a weekly output of twenty-seven kilograms of zirconium. In 1952 its output rose to 122 tons. The greater portion was rolled into sheet and structural shapes for nuclear reactors.

But zirconium comes in useful not only at nuclear power plants, atomic icebreakers or submarines. Zirconium is an efficient alloying agent for steel. In its effect it is similar to vanadium and does its job of a scavenger as efficiently. Zirconium steels are very ductile and retain their mechanical strength at high temperatures. Many grades of armour, stainless and fire-resistant steel contain zirconium.

Additions of zirconium have a wholesome effect on aluminium alloys as well. The alloys become denser and more ductile. Their mechanical strength almost doubles. There is also a sharp increase in resistance to corrosion, especially to the action of sea water.

When added to copper, zirconium raises its strength after a suitable heat-treatment half as much again while reducing its electrical conductivity but little.

Of late zirconium has come to be used in the production of fine-grained magnesium-base alloys. A magnesium-base alloy containing four to five parts zinc in a hundred and six or seven parts zirconium in a thousand is twice as strong as a magnesium-zinc alloy without an addition of zirconium.

Zirconium is added to lead bronzes, copper-cadmium alloys, manganese bronze, and nickel alloys.

But zirconium also works on its own. We've already mentioned its services in nuclear engineering. It has also entered into a strong alliance with the vacuum-tube industry; because of its ability to absorb gases at high temperature, the metal is used as a getter in vacuum tubes so as to maintain a high vacuum in them.

Machine designers are planning to make zirconium into parts for centrifuges, pumps, chemical condensers, pistons, connecting rods, tie-rods and other components for internal-combustion engines, blades for steam and gas turbines, components of jet engines, and a variety of other products.

Still wider use has already been found for zirconium oxides. They are very refractory, melting anywhere between 2700° and 2900°C. They are manufactured into a multitude of refractory ceramic products.

Hafnium is an intimate companion of zirconium. They always occur together, in the same ores, and are difficult to separate. Although hafnium is more refractory than zirconium (it melts at 2230°C) and is almost twice as heavy as zirconium (its specific gravity is 11.4), it remained unnoticed for a long time. It was not until 1923 that the Hungarian Hevesey and the Dutchman Coster discovered it in Copenhagen by X-ray analysis. They named it hafnium from Hafnia, the Latin name of Copenhagen. As a matter of record, Mendeleyev predicted its existence in 1870, and the famous Danish physicist Niels Bohr described its properties well before its discovery.

At one time metallurgists were after pure hafnium. They did not care about zirconium or how pure that element was. Now just the opposite is the case. Nuclear engineering needs zirconium of utmost purity. The great tendency to absorb thermal neutrons makes the presence of hafnium in zir-

conium most objectionable. So every effort is made to prepare zirconium as pure as possible and hafnium-free above all.

Few commercial uses have been developed for hafnium, though the high melting point and high electron emission of the metal suggest uses in radio tubes, incandescent lamps and rectifiers, and as cathodes of X-ray tubes. But again there are other, more manageable materials for these purposes. So hafnium is still to win the right to be used in industry.

Hafnium's neighbour on its right is the metal tantalum. Its name comes from Tantalus, the mythological king of Phrygia, a son of Zeus and the nymph Pluto. For his crime before the gods he was consigned after his death to the nether world and compelled to suffer from the constant pangs of thirst and hunger. Though he stood up to the chin in cool, crystal-clear water and always had before him the offer of the richest fruits, both receded from him as he tried to drink or eat. Not a single drop of water could get into his inflamed mouth.

When in 1802 Ekeberg of Sweden declared the discovery of a new element, he named it tantalum because it was incapable of "drinking" acids. Some time later it was learned that the scientist had worked with a mixture of two metals. One of them retained the name of tantalum. Ductile tantalum was first produced in Germany by W. von Bolton in 1903, or a century after its discovery.

Tantalum looks like platinum. In air it is covered by a very strong, greyish film of oxide which prevents its further oxidation. On heating to 400°C the film takes on an attractive sky-blue tinge which remains on cooling.

Tantalum is a heavy metal. Its specific gravity is 16.6. It is refractory, melting at 2850-3000°C. Only tungsten and rhenium melt at higher temperatures. Tantalum boils at 5300°C, which is only 700 degrees below the temperature on the surface of the Sun.

Tantalum is a strong metal. The ultimate tensile strength of tantalum wire is 92 kilograms per square millimetre, better than some steels have.

As to chemical stability, tantalum is second only to the noble metals and then not in all cases.

Naturally, this sort of metal could not be overlooked in technology. Indeed, it was put to practical use in the same year 1903 when it was first prepared as a ductile metal. Tantalum became the first practical metallic filament for electric lamps. Later on it gave way to the cheaper and more refractory tungsten. Yet tantalum is still being used in vacuum tubes.

Tantalum is very resistant to abrasion. It vies with iridium as a material for tipping fountain-pen nibs.

Tantalum is a welcome material in the chemical industry. Among other things, it is usual to make tantalum condensers for the manufacture of hydrochloric acid.

Tantalum is made into spinneretes for rayon and into extrusion rings used in the production of synthetic sausage casings.

For a long time surgeons felt helpless when it çame to a ruptured artery. They had learned how to join bone fractures, how to stitch up a severed vein, or to restore damaged nerves. But they did not know how to repair a ruptured artery.

A good many great surgeons like Pirogov tried various suturing techniques. After hours of painstaking labour they would join the thin, elastic tubes, but as often as not a plug of clotted blood, called a thrombus, would block the vessel at the joint, stopping the stream of blood through the organism. The surgeon's mastery would thus end in a failure.

The situation remained as described until about twenty years ago, when the Soviet engineer V. Gudov invented a mechanical suture applicator.

His applicator is a small contrivance consisting of several dozen chrome-plated components. The ends of the blood vessel to be joined are clamped in the jaws of the applicator; the jaws are brought together; the surgeon presses a button and metallic clips, very much like those used in exercise books, reliably join the ends of the vessel.

The clips are made of tantalum. This remarkable metal causes no harm either to tissues or the organism as a whole. Tantalum is also used to make nails for fractured bones, plates for skull repair, and woven fabric to join ruptured muscles. This is a most unusual use for a metal.

The year before Ekeberg came out with his announcement about the discovery of tantalum, Charles Hatchett of England had reported his discovery of columbium. It is believed that both men were working with mixtures of the oxides of tantalum and columbium, since neither spoke about the presence of two elements. Finally in 1844, Rose of Germany said he had found two elements in the oxide extracted from columbite. One, he said, was tantalum and the other he named niobium after Niobe, daughter of Tantalus. It is still called columbium in Britain, but the International Union of Pure and Applied Chemistry officially designated it as niobium in 1949, and this name is now almost universally accepted.

Niobium and tantalum are almost invariably found together, and due to their similarity in chemical properties their separation is a difficult business. It was not until 1907 that metallic niobium was first prepared.

Niobium is a very refractory metal; it melts at 2415°C and boils at 3300°C. Its specific gravity is 8.6, which is rather low. In strength it roughly

compares with carbon steel, and displays medium chemical activity. Its commercial use is mostly as an alloying addition to steels. Chrome-nickel steels carry five to eight parts niobium in a thousand. Because of its affinity for oxygen and nitrogen, it is an excellent getter for electron tubes.

METALLOIDS

The elements on the right side of the Periodic Table are referred to as non-metals. Frankly speaking, however, there is no clear distinction between metals and non-metals. As the chemist would define them, metals are elements which lose outer or valence electrons in forming compounds and non-metals are those which accept electrons. Many elements, however, do one way in some compounds and the opposite in others.

It is said that on dissolving in water oxides of metals form strong bases and those of non-metals strong acids. But again there are "amphoteric" elements; their compounds act basic towards strong acids and acidic towards strong alkalis. Even iron, this unquestionable metal by all standards, behaves like a non-metal in some compounds. But the most amphoteric of all are the so-called metalloids, or semimetals. These elements are frequently semi-metallic in some properties and decidedly metallic or non-metallic in others.

Take volume 27 of the Large Soviet Encyclopedia and open it on page 270. There, in the table of abundance of the elements in the Earth's crust, you'll find arsenic, selenium and tellurium classed as metals. They are also classed as metals in the table of properties of the metals on page 244. Now open volume 29 of the same Encyclopedia at the entry on the non-metals. There you'll find arsenic, selenium and tellurium classed as non-metals.

Is this a mistake? No, it is not. Simply a lack of coordination between the two contributors, which can be easily explained. Each can make out his case forcibly. This is why I've added a few short notes on the metalloids at the risk of stealing some of the attraction from a future book on them.

Selenium is another element with a name borrowed from astronomers. Berzelius, who discovered it in the flue dust from sulphuric acid production in 1817, named it after *Selene* (the Greek for "moon").

Although scattered in small amounts, selenium often occurs native in conjunction with sulphur. In effect, it resembles sulphur in many respects. It is also found in the form of selenides of copper, silver, mercury, and so on.

The main sources of selenium at present are the flue dust from the roasting of pyrites in the making of sulphuric acid, and the anode mud from the

electrolytic refining of copper. The anode mud, or slime, picks up as much as fourteen parts selenium in a hundred. Today it is the source of most of the world's selenium.

Like sulphur, selenium presents a number of allotropic forms. If molten selenium (which melts at 214°C and boils at 685°C) is slowly cooled, hexagonal or metallic selenium is formed. It is a good conductor of electricity and the most stable modification. If cooling is rapid, a brittle, lead-grey mass known as amorphous selenium is formed. Like any amorphous material, it simply softens on heating under 50°C. On further heating it changes to hexagonal selenium through crystallization. Then there is the red powder, produced by the rapid cooling of selenium vapours.

Selenium is a typical semiconductor.

Some twenty years ago people dealing with electricity cared little about semiconductors. They needed conductors to make wires, busbars and contacts, and also dielectrics to make baseplates, panels and insulators. Semiconductors, they reasoned, were no good in either capacity.

Yet semiconductors have remarkable properties. Their resistance to electric current varies as the ambient conditions change. When cooled to a temperature very near to absolute zero they become almost ideal dielectrics, and not superconductors as metals do. These and other properties have brought semiconductors into the public eye. Today many industries are pinning much hope on them.

Semiconductor devices have replaced radio valves in many uses. They are smaller in size, draw very little power by comparison and, what is most important, have practically unlimited service life. With them radio engineers have built robust and reliable broadcast radio receivers the size of a match-box or even smaller, and TV sets consisting practically of a screen alone. They are flat and can be hung up on a wall like pictures.

Semiconductors have offered a better choice as rectifiers compared with motor-generators and rotary converters with revolving parts, or mercury-arc rectifiers with huge glass bulb holding mercury and its vapour—units which call for utmost care in operation. Semiconductor rectifiers have none of these. This is why they hold out special promise to railway engineers who are planning to change over to alternating current for traction on a large scale.

Among the many remarkable properties of semiconductors is their ability to turn heat directly into electricity. It is called the Seebeck effect. If you place two junctions of dissimilar semiconductors in the same circuit and heat one of them while holding the other cold, an electric current will flow round the circuit. In fact, this happens in any circuit containing two junc-

tions of dissimilar metals. But with semiconductors the current is so large that thermoelectric generators using an oil-lamp or an oil-stove as a source of heat can power domestic radio sets. Such generators have been in use in the Soviet Union for some time already. Looking into the future, we can see this effect utilized in big commercial power plants. Such a plant, much simpler than any existing fuel-fired station, will have its firebox covered with the "hot" junctions of semiconductors so that they face the flame. Their "cold" junctions will extend outside to be cooled with torrents of atomized water. Thus a temperature difference will be maintained between the "hot" and "cold" junctions, and the current generated by a thermoelectric cell increases directly with this difference.

Such a power plant is only an idea, though a bold one. For we haven't found yet a commercially feasible and economical method for the direct conversion of heat into electricity. We're just feeling our way in this field. The efficiency of the best thermoelectric cells is one-fourth to one-fifth of that of modern fuel-fired stations. Much has yet to be done before the semiconductor power plant can become a hard reality.

In 1834 Peltier discovered what is the opposite of the Seebeck effect. In the Peltier effect, as it was called, heat is liberated or absorbed at the junction of two different conductors when an electric current passes through the junction. The junction is either heated or cooled depending on the direction of the current. With semiconductors this heat transfer is so large that it can be utilized in domestic and portable refrigerators. They are more economical and durable than any others.

As if it were not enough, semiconductors show the so-called photoelectric effect. When illuminated, some emit electrons from the surface, others build up a potential difference across their junction, and still others show a drop in their resistance to the flow of an electric current. And the respective semiconductor devices are called photoemissive, or simply, photocells, photovoltaic cells, and photoconductive cells. Thus cesium gives photoemissive cells and selenium produces photoconductive cells. Incidentally, selenium can also be used in photovoltaic cells, rectifiers and other devices. In all of these applications we use its ability to drop in resistance a thousand times or more when illuminated.

Next comes tellurium. It is as much similar to selenium as selenium is to sulphur. Most of what has been said about selenium holds for tellurium.

It was discovered in 1782 by F. J. Müller von Reichenstein who extracted it from a gold ore. He sent a sample to the famous Swedish chemist Torben Bergman for analysis. However the sample was small and Bergman was

unable to identify it properly. In 1789 Kitaibel, a Hungarian chemist, independently discovered the same element which remained unnamed until 1798 when Klaproth suggested the name tellurium from the Latin "tellus", the earth.

Tellurium is more metallic than selenium. It shows a silvery-grey lustre and is brittle and unmalleable when cold. It melts at 425°C and boils at 1390°C. At room temperature air does not attack it. Like selenium, it occurs native. Commercially it is got from the same sources as selenium.

Although the electric conductivity of tellurium, which is greater than that of selenium, does not change with temperature, it does change with pressure, increasing as the latter increases.

Small amounts of tellurium markedly improve the corrosion resistance and mechanical properties of lead. Lead alloyed with 0.5 per cent tellurium goes to make apparatus for the production of sulphuric acid. This alloy has a service life twice as long as pure lead.

When added to stainless steels, copper, or copper alloys, tellurium improves their machineability. As an addition to babbitt metal tellurium raises its hardness, durability and wear resistance.

Its other uses include addition to aluminium to improve ductility; toning of photographs; staining of silver to give "platinum" finish; colouring glass and ceramics (blue and brown); and manufacture of organic dyestuffs.

On top of all, tellurium and its compounds hold out great promise for use in semiconductor devices. Before long it may take its place beside better-known semiconductors such as selenium and germanium.

The existence and properties of germanium were predicted by Mendeleyev fifteen years before the German chemist A. Winkler discovered it in 1886. Its name bespeaks the nationality of its discoverer.

Until quite recently this remarkable silvery-white metal was just a laboratory curiosity. Today man has come to rely heavily on germanium, and its production has been steadily expanding. Its chief use is in the manufacture of electronic semiconductor devices. Germanium crystals can operate as oscillators, modulators, voltage regulators and polarizing devices. But in all of these devices it must be exceedingly pure. Impurities present only as a few parts per thousand million can do much harm.

Germanium is a very scattered element. It is found in almost all rocks, including granite and gabbro. But everywhere its concentration is very low. In the Soviet Union the principal sources of germanium are flue dusts and coal ashes from producer-gas units. Another source is the waste from the treatment of zinc sulphide ores. The annual production of germanium in the 1950's was several tons.

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Since germanium is very brittle, it cannot be mechanically worked. Instead thin wafers of this element are prepared by cutting a germanium block with a diamond saw. Shapes are produced by melting germanium in suitably fashioned crucibles. Germanium melts at 959°C and boils at 2700°C.

In addition to its semiconductor applications as an element of extreme purity, germanium is also used in alloys. An aluminium-germanium alloy is very good for the cathodes of radio valves. A gold-germanium alloy has good colour and is harder than pure gold. It melts at 450°C and can therefore be applied by simply dipping an article in a bath of molten alloy. When added to magnesium, germanium improves its mechanical properties, especially fatigue strength and resistance to corrosion.

Finally we've come to arsenic, selenium's neighbour in the Periodic Table. Its discovery dates a long, long way back. Ancient Greeks used it in paints and drugs; in ancient Rus people killed mice and rats with it. Incidentally, the Russian for arsenic literally means "mousepoison".

Arsenic, as it is most commonly known, is a brittle, steel-grey metal. But we also know two more allotropic forms of arsenic, black amorphous and yellow cubic. When heated to about 600°C under atmospheric pressure, arsenic sublimes. It is under a pressure of thirty-six atmospheres that arsenic can be melted (at 814°C).

Arsenic has no use as a pure metal. But when alloyed in small quantities with lead, it increases the hardness of lead-base bearing metals and forms more perfect spheres when making lead shot. Small amounts increase the corrosion resistance and toughness of copper, but in steel and electric grades of copper it is an undesirable and, indeed, very harmful impurity.

On the other hand arsenic has very many uses in compounds, mostly toxic, and most of the arsenic produced is utilized in their form.

Such are the elements lying between the metals and the non-metals in the Periodic Table.

THE REST OF THE RARE METALS

In 1871 Mendeleyev predicted the existence of what he named "eka-aluminium" and summed up its properties as follows:
(a) it must be low-melting;
(b) it must not tarnish in air;
(c) its specific gravity must be 5.9;
(d) it must decompose water vapours at red heat.

When in 1875 the French chemist L. de Boisbaudran discovered "eka-aluminium", a soft silvery-white metal which he named gallium after his native country, it was found that:

(a) it melts at 30°C;

(b) it oxidizes only at red heat;

(c) its specific gravity is 5.9;

(d) it decomposes water vapours at elevated temperature.

Gallium will melt right in your palm. When liquid, it looks like mercury. It can remain liquid down to minus 40°C like any supercooled liquid.

Since the metal is liquid at 30°C and does not boil below 2200°C, it is a very good filling material for high-temperature thermometers. Instead of ordinary glass, fused quartz is used for making the bulbs and capillaries of such thermometers which operate reliably up to 1300°C.

Some gallium is used in alloys with bismuth, lead, cadmium, indium, tin and thallium. These are so-called fusible alloys melting at 16°, 20° or 45°C. Gallium is widely distributed in nature, but only in minute quantities. Commercially gallium is got from zinc flue dusts, electrolytic zinc solution residues and residues of the Bayer alumina liquors.

Indium was discovered in 1863 by F. Reich and T. Richter of Germany who were checking a sample of zinc blende for thallium. During spectroscopic examination they noticed a bright indigo blue line which had never been reported before. Later they isolated a new element which they called indium from the indigo blue line of its spectrum.

Although the discoverers of indium gave it a specific gravity of 75.6, Mendeleyev changed the figure to 113 on the strength of his Periodic Law. Further studies proved him right. That was one of the earliest practical applications of the Periodic System.

Indium is a soft metal very much like gallium in properties, though it melts at a higher point (155°C) and boils at a lower temperature (1450°C). Indium metal is unaffected by air at ordinary temperature and slowly corrodes in water.

Recent decades have seen a steady rise in the use of indium. In 1942 the world outside the Soviet Union produced twenty tons of this metal.

The chief use of indium is in high-performance sleeve bearings. In them the indium is plated and diffused on the bearing surfaces to reduce friction, to give good resistance to corrosion and to eliminate seizure.

Liquid indium will "wet" glass, and thus may be used for the making of mirrors. Although it is not so reflecting as silver, indium offers the advantage of not tarnishing in air.

We've already mentioned fusible alloys containing indium. One such alloy containing one half indium and one half tin is used in the vacuum-

tube industry and research laboratories. This alloy has the rare property of wetting glass and is therefore used to seal glass to glass and glass to metal.

Indium is got from the wastes of zinc and lead production.

Thallium was discovered by W. Crooke of England in 1861 and named from the bright green line on the spectroscope, because "thallus" in Latin refers to the bright green tint of fresh vegetation.

Thallium is also a widely scattered element although it is as abundant in the Earth's crust as mercury. It usually has a bluish-grey tinge, but a freshly cut surface will have a metallic lustre which rapidly dulls on exposure to air. It is softer than lead and harder than indium. It is highly malleable but not tenacious. On heating it burns with the evolution of brown fumes. It melts at 303°C and boils at 1457°C. Its specific gravity at 20°C is 11.85.

The first important use of thallium was discovered in 1920 when a German company introduced a rat poison based on thallium sulphate. This is still the most important commercial use for thallium. Other compounds of thallium are also strong poisons and are used to kill rodents and ants.

Thallium sulphide has found use in photoelectric cells. Small amounts of the metal may be added to lead-base bearing alloys to increase the resistance to pounding. The chief use of metallic thallium at present is, however, in optical glass of high refractive power.

Thallium is mainly recovered from the wastes and by-products of sulphide ore treatment.

Cadmium, indium's neighbour in the Periodic System, was discovered by Strohmeyer of Germany in 1817. In the middle ages its name was applied to zinc ores.

Cadmium is a bluish-white metal, malleable and tenacious. It takes a high polish and does not tarnish in air under ordinary conditions. It melts at 321°C and boils at 767°C.

Cadmium is added to type metal, is used as a plating material on iron and steel, and is also employed as an addition to the cadmium-copper alloy fabricated into trolley wires. Such conductor wires stand up well to abrasion. Alkaline storage batteries use cadmium plates.

The metal is usually recovered as a by-product in the treatment of zinc ores. Some of them contain as much as one part cadmium per hundred parts zinc. In 1959 the world outside the socialist countries produced over seven thousand tons of cadmium.

This brings us to the end of our brief review of the rare metals that have not been included elsewhere in the book.

CONCLUSION

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Volume 27 of the second (Russian) edition of the Large Soviet Encyclopedia has a very interesting table on page 261. In the table the metals are not arranged according to atomic weights, specific gravity, chemical activity or occurrence in nature. The table shows when any one of the metals (whether in pure form, as an alloy or as a compound) was first used in the service of man.

Look at the metals under the first heading. The heading covers a long, long period from those days lost in the abyss of time when man first picked up a gold nugget to 3500 B.C., when powerful states already existed in Messopotamia and Egypt. During this period, extending through millenia, man came to use only six metals, iron, gold, copper, tin, lead and silver.

The next heading covers a much shorter span of time from 3500 B.C. till the beginning of the present era. As you can see, man was now advancing faster on the road of progress. To the six older major metals, as they are often called, he added ten more. Those were bismuth, potassium, calcium, cobalt, magnesium, arsenic, sodium, mercury, antimony and zinc.

The third heading is even shorter than the second. It covers the period from the beginning of the present era to the 19th century. It includes the heart-chilling gap of the Dark Ages when the witch-hunting clergy stopped any beat of human thought and any progress in knowledge. Eleven more metals were added during this period. They are barium, iridium, lithium, manganese, nickel, platinum, strontium, thorium, chromium, cesium and cerium.

The fourth heading takes us as far as 1920, or through a period of less than a century. But those few decades were more filled with discoveries than the prehistoric millenia. Man's progress become fantastically rapid, and in this advance he needed many more supporters. So fifteen more metals were added: aluminium, vanadium, tungsten, cobalt, magnesium, molybdenum, osmium, palladium, radium, rhodium, ruthenium, thallium, titanium, uranium and zirconium.

Very few metals not yet used by man were left in the Periodic Table. And during the next decade between 1920 and 1930 cadmium came to work

for man. The years between 1930 and 1940 saw four more metals be put to work. They were beryllium, indium, niobium and tantalum.

It would seem that scientists and engineers were anxious to find use for some new metal. Actually quite the opposite is the case. In designing a new machine or working on a new project, the engineer tries above all to manage with known materials. Their production is a routine affair, and their properties have been tested. They will not let him down. He turns to new materials only when the old ones have proved inadequate for one reason or another. And he does so reluctantly, for each time he invites a new metal to serve him, he is in for a good share of difficulties, failures and setbacks.

Another decade went by, from 1950 to 1960, and another five metals took up work with man. They were gallium, germanium, metallic calcium, neptunium and plutonium.

The heading next to the last lists the metals that have not found any use. True, the compilers warn the reader that they cannot vouch for the authenticity of their data; in most cases information about their uses is classified. Some of the metals listed as "unemployed" have already taken up one job or another. It is not important, though, for if they haven't, this will happen before long. These "unemployed" metals (in alphabetic order) are actinium, dysprosium, erbium, europium, gadolinium, hafnium, holmium, lanthanum, lutecium, neodymium, polonium, praseodymium, protactinium, rhenium, rubidium, samarium, scandium, terbium, thulium, ytterbium and yttrium.

Some of them are rare-earth metals, other occur in very minute quantities in the Earth's crust. Sooner or later they will be put to work, for each of them has something peculiar about it, and this "something" man can use to his advantage. Simply their turn has not come yet.

Now we've reached the last heading. Under it are placed the elements man has prepared artificially. The table gives ten of them, leaving out neptunium and plutonium which can be found in trace amounts in pitchblende. Since the volume was published, five more man-made elements have been added to the list. There are now twice as many elements as the metals under the first heading. Among them are the transuranium elements americium, berkelium, californium, curium, einsteinium, fermium and mendelevium, and also the elements astatine, technetium and francium which fill the vacant places in the middle of the Table.

Now we are in the position to add element 102 still known as nobelium, element 103 named lawrencium, and element 104 named kurchatovium.

The Table does not tell us many things: about the involved and ingenious processes by which metals are extracted from their ores where Nature holds them under seven seals; about the jobs that the new metals can do; about the huge proportions to which their production has expanded. Yet it gives a clear idea about man's rapid ascent on the ladder of progress.

Today man is the master of the Earth. Tomorrow he will be the master of the Universe. To hold his sway he needs materials for machines taking him deep into the Earth's insides and for craft which will take him across outer space. He needs materials for giant electronic brains and for supertall TV masts. Many of these materials he is finding, and will be doing so for a long time to come, among the metals of his home planet.

And what he will fail to find, he will make himself —to his taste and needs. He is already making materials non-existent in nature. Their list is too long to be given here.

Man can do whatever he thinks worthwhile. For there is no limit to his daring and his potentialities.

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